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SANDERLING

FINAL REPORT : Part C

A Research Study into KBS for Command and Control
in Naval and TMD Applications

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The SANDERLING Final Report comprises the following three volumes :

- The **EXECUTIVE SUMMARY** provides an overview and summary of the study, including its conclusions and key findings, but not including specific detail on suggested projects;

- **PARTS A & B** cover the method and direction of the study, and include details of the technology analysis as well as the initial thniking behind the projects;

- **PART C** of the Final Report defines the recommended research programme in some detail. It describes suggested projects (including form, content, cost and resources), overall programme structure and recommendations on how to proceed.

SANDERLING

Final Issue

April 1990

SANDERLING Final Report :

PART C The Research Programme

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PART C THE RESEARCH PROGRAMME

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1. INTRODUCTION

1.1 Background

Recognizing the potential to be gained in command and control (C^2) systems from knowledge based systems (KBS) and the related field of artificial intelligence (AI) the Admiralty Research Establishment (ARE) set up the Technology Demonstrator Programme (TDP) and the associated Technology Demonstrator System (TDS). This work is addressing many of the practical and immediate problems associated with the application of KBS to data fusion in the context of Naval C^2. The TDS project is progressing towards sea trials as an engineered data fusion demonstrator. The parallel TDP is providing the supporting research. In addition, ARE is undertaking other research via prototypes, theoretical studies and experiments aimed at establishing a wide capability in KBS-based C^2.

Many of the functional characteristics and technical problems associated with Naval C^2 are similar to those in other large and complex military applications. In particular it was realised that there was significant commonality with the Strategic Defence Initiative (SDI)/Theatre Missile Defence (TMD) scenario. As a result a joint approach to research in the technology was agreed between ARE and the SDIO/SDIPO. A major part of that approach is a programme of research extending over a total of four years. The programme will link to the current ARE research activities and will consist of a number of research projects to be undertaken by ARE, UK industry and universities.

The first phase is a 6 month study to define the contents of the research programme. The study commenced in October 1989 and is code-named SANDERLING. It has been undertaken by a consortium of three companies, working in close association with ARE and the SDIO. The consortium comprises Logica Cambridge Ltd, BAe (Sowerby Research Centre) and Cambridge Consultants Ltd. Logica are the prime contractors and overall project managers.

1.2 Aim

The aim of the SANDERLING study is to generate a KBS research programme in C2 for Naval and TMD applications.

1.3 Report

The results of the study are being reported in three parts. Parts A and B concentrate on the analysis phase of the study. Part A introduces the requirements of the study, the goals and objectives of the work and the approach and methods used. Part B shows how the six technology research streams for the programme were generated and explores the research issues and priorities for sub-topics within each technology stream. This analysis is complemented by an applications perspective and culminates in a set of initial ideas for SANDERLING research projects.

1.4 Part C

Part C of the report uses the results and data from the analysis to define a set of research projects and a recommended research programme. It consists of :

- Section 2 sets out the strategy for the programme and initial top-level views on priorities and criteria for the selection and evaluation of individual projects.
- Section 3 explains the way in which the projects have been categorised and the method used to formulate the programme.
- Section 4 provides a summary description of each project. This is supported by Annex C1 which is a tabular summary of all projects and Annex C2 which contains a more detailed two to three page description on each project.
- Section 5 looks at the sum of the projects from the perspective of the overall technical objectives and the priorities in each technical stream and sub-topic.
- Section 6 sets out the evaluation criteria for selecting projects to include in the programme and draws up a preferred options short-list from the overall total of projects.
- Section 7 then describes how projects fit into the overall programme in terms of effort, costs, dependencies and timetable.
- Section 8 summarises the recommendations and results of the study.

1.5 Acknowledgements

The SANDERLING consortium wish to acknowledge the support given to the project by staff at ARE, the SDIPO, the SDIO and their associated contractors. We are also grateful for the help and advice we have received from many others, including our own external consultants on the Technical Review Panel, and the members of the Electronics and Business Equipment Association, who contributed valuable background material to the study.

Input from all these sources has contributed significantly to the results of the study and to the shape and form of the research projects and programme. We have naturally been particularly concerned to respond to the comments and feedback from reviews carried out by the SDIO and ARE and to work with them on the design of the projects and programme. However, as always with such tasks, only a co-ordinated proportion of such input can finally be included.

2. STRATEGY FOR THE RESEARCH PROGRAMME

This section sets out the strategy on which the research programme is based. A review of the programme objectives and assumptions leads into the key aspects of the strategy. These are then developed into a framework for the research programme and a discussion on the balance of projects across a number of dimensions. Finally the criteria used to evaluate the projects and programme are summarised.

2.1 Objectives

2.1.1 Level One Objectives

The goals of the research were analysed in section 2.2 of Part A and resulted in three level one objectives for the research programme, namely:

- to advance the capability to deploy at sea Naval KBS-based C^2 systems;
- to extend the functionality of current KBS-based C^2 demonstrator systems;
- to provide the basis on which to deploy and deliver KBS-based solutions to functional requirements for TMD C^2 systems.

The first objective is primarily focussed on the engineering, performance and development issues associated with moving the current technology out into operational systems at the earliest date. It also includes a strong element of user justification, benefit assessment and risk reduction. The time horizon for this objective is short to medium term (1 to 6 years).

The second objective accepts that the capability of current technology to provide the full range of future functional requirements will be limited and that work is necessary to investigate and explore more advanced ideas and to incorporate these into future demonstrators. This objective has a medium to long term time horizon (6 years or more).

The third objective combines the two previous objectives but concentrates specifically on the TMD domain with a medium to long term time horizon (5 to 15 years).

(See Part Part C Section 2.2 for further definition of assumptions on time horizons.)

2.1.2 Level Two Objectives

Section 2.2 of Part A expands the level one objectives into two further levels. Input to these objectives includes ARE's documents on objectives for the TDS and TDP programmes (Byrne 1989, Miles 1989a, Narborough Hall 1989). The level two objectives are summarised below:

Deployment Capability

- To provide practical support to the TDS trials deployment via: training and assistance in the experimental use of the TDS; modifications for performance optimisation; evaluation and assessment of TDS capability;

- To extrapolate TDS experience to operational system deployment by examining the feasibility of scalar and performance extensions to meet future operational requirements;

- To make use of the TDS deployment to achieve objectives such as: define KBS development methods; establish metrics for assessing system performance; assess the level of user/organisational impact; refine the user requirements for advanced C^2 systems; determine the feasibility of the TDS design and systems architecture; define a growth/development path for the TDS.

Enhanced Functionality

- To extend, via prototypes, the functional support provided by KBS further into non-data fusion areas such as situation assessment, resource allocation and planning;

- To investigate and discover new techniques for knowledge representation and manipulation;

- To investigate novel/non-KBS areas of significant potential advantage such as distributed AI, machine learning and neural networks.

TMD Requirements

- To explore and define solutions to development techniques in critical aspects such as: verification, validation, specification and maintenance; performance limitations and improvements; and the significance of Human Computer Interaction (HCI) issues;

- To extend the underlying techniques and capability in functional aspects other than data fusion;

- To investigate novel areas of significant potential advantage such as machine learning and neural networks.

2.2 Assumptions

2.2.1 Time Horizon for the Research

The research programme will be aimed at generating results that can be used operationally beyond the three year period of the programme itself. Although some research projects will stand-alone and will deliver complete results within the three year period, others will be the start of further research. The timing assumptions used are based on supporting a standard procurement life cycle. The detailed assumptions and rationale can be found in section 2.2 of Parts A and B. Summarised, they are as follows:

	Naval Objectives	TMD Objectives
Short Term	<3 years	<5years
Medium Term	3-6 years	5-10years
Long Term	>6 years	10-15 years

The main reason that the times are different between the two major application areas is that the Naval objectives place more emphasis on supporting trials and deployment in a shorter timescale than would be appropriate to TMD/SDI.

2.2.2 TMD Scenarios

The SANDERLING projects and programme have been primarily based on the the United Kingdom Architecture Studies (UKAS) and the Battle Management Command, Control and Communications (BMC^3) Studies. TMD related research projects consequently anticipate deployment of KBS decision support within the C2 context set out by those studies. However, this study has also taken into account wider Continental US (CONUS) issues as reflected in the Strategic Defense Systems (SDS 1989) system description. See Working Paper 3 section 4 for details.

In particular it was recognised that there is a range of possible scenarios and a considerable requirement for 'man in the loop' in the SDI context. Thus scope for HCI issues to be fully addressed in the context of TMD research.

2.2.3 Relationship to ARE Programme and Plans.

The study input has included an indication of ARE's future research plans. We have endeavoured to include in our list of SANDERLING Projects those elements of ARE plans that are not yet underway and that ARE have indicated are a priority (Byrne 1990).

The timetable for the research programme relates to the timetable for ARE's existing work programme in so far as we are aware of it (ARE Staff 1990, Heath 1990).

Understanding of the TDS was based on ARE's requirement specification (Miles 1989a).

2.2.4 Cost / effort

Estimates of effort in man years are based on an analysis of each individual project and on the assumption that the work would be carried out by skilled and competent research staff. Where appropriate we have indicated the expertise required to perform a given project. This applies particularly to projects that fall within the £7M budgetary limit and are referred to as Type A. (Specific details on sources of relevant UK expertise can be found in Annex B1.)

No explicit assumptions have been made about how much of the programme would be done by ARE personnel and how much would be done by external sources. Where a major university input is envisaged on a particular project this is stated.

An average figure of £80K per annum per person has been used for external industrial support or ARE staff. This may be optimistic and will be too low for some projects requiring a high proportion of senior staff. A figure of £40K *per annum* per person has been used for university staff. Hardware, software and other material costs are indicated where appropriate or the assumptions for their exclusion are stated (eg. a project expects to use existing ARE equipment.)

The effect of inflation has not been included in the costings, neither has any allowance for expenses. The estimates are approximate and for budgetary purposes only.

2.3 Key Aspects

The overall strategy for the research programme comprises the following key aspects:

- Special and critical issues

  Projects included in the programme must concentrate strongly on specific aspects and critical gaps in the technology. This is driven by the size of the budget, which is is not large compared to the size of a single large ESPRIT (European Special Programme for Research in IT) project in KBS. There is also little point in doing general purpose work that is going on elsewhere.

- Maximum linkage to other programmes

  The greatest possible use must be made of the existing and planned research programme at ARE and at other establishments such as RAE and RSRE. This will avoid duplication, make the most of lessons learnt already and will reinforce the work in those related areas. This will also apply to scenario generation and data, where common sources of information should be used in the first instance by SANDERLING projects.

- Strong support for the TDS

  The success of the TDS is crucial for KBS supported Naval Data Fusion and further C^2 functions. There must therefore be a strong emphasis in the programme on supporting and enhancing the use of the TDS demonstrator. This is reflected by the inclusion within the programme of the priority projects identified by ARE AXT(R).

- Build two major TMD prototypes

  An early prototype in the TMD domain is essential to provide a means of carrying out other research into development techniques, (eg. verification and validation) and as an example of KBS supported functionality in SDI. This 'development methods' prototype should be commenced at the beginning of the programme and should complement other SDIO work in the UK. In addition, one other major prototyping project should be undertaken in the SDI/TMD domain as the basis for investigating a number of advanced issues.

- Explore advanced capability

  Research projects must look beyond the current generation of TDS work and provide a basis for more advanced capability. This includes new approaches to knowledge representation and manipulation, and the exploration of some speculative areas with high potential pay-off, such as machine learning and distributed decision making.

- Practical demonstration of the technology

  Research should concentrate on experimental projects that test and demonstrate practically the application of the technology. There should therefore be an emphasis on prototype projects. There will be limited opportunity and funding for state of the art studies, but projects that include new theoretical studies can be included.

- Plans for an advanced battle management and C^2 demonstrator (BMC^{2}D)

  The technology embedded in the TDS can be extended to some extent to include higher levels of functionality than Data Fusion in the Naval context. However, this capability is limited and could restrict future requirements to use new and later research results, especially in the SDI/TMD domain. There is also other work in the UK on TMD which will need to be integrated with the SANDERLING research projects. The programme should therefore include the concept of an advanced Battle Management and C^2 demonstrator (BMC^{2}D). This would provide a focus for aspects of SANDERLING research. During the programme an outline specification should be undertaken. Design and implementation would be a follow-on activity. At this stage it is assumed that a single BMC^{2}D will cover both Naval and TMD domains; it may however become clear during the programme that separate demonstrators are necessary and can be justified.

- Joint programme

  This is a joint research programme and it is therefore important that there is maximum synergy between Naval and TMD themes and a roughly equal balance of resource between them in the programme. The range of projects should include those that jointly benefit both domains (eg. KBS development methods) and some that are more specifically focussed on Naval or TMD needs. (eg. direct support to the TDS). Most projects should produce some benefits for both domains.

- Programme management

  Although this programme will not be large in total value compared to national and international KBS research programmes, there is a planned budget of £7m and approximately 20 projects with a range of tightly defined objectives. It is therefore essential for success that adequate provision is made to manage and evaluate the programme efficiently.

2.4 Overall Framework

The overall framework of the research programme and its relationship to current and planned activities is is set out in Figure 1. Projects will fall into two major categories:

- Type A : Applied Research;
- Type B: Enabling Research.

Additionally, a certain amount of effort (approx 10%) will be devoted to support projects relevant to all categories of research.

2.4.1 Applied Research

This will absorb approximately 70% of the resource and will be primarily related to existing and planned work associated with:

- deploying the TDS in an integrated C^2 system;
- building and using two TMD related prototypes;
- enhancing the naval laboratory demonstrators and prototypes.

It is envisaged that research projects in this area will be strongly driven by the functional/application themes identified from UKAS and BMC^3 studies and Naval operational requirements. It will also be closely coupled to the current ARE planned research. Individual research projects will be strongly linked to these functional research themes. All projects in this category will address measurable short term objectives and will produce relevant deliverables within the timescale of the three year programme.

2.4.2 Enabling Research

This will absorb approximately 20% of the resource and will be related to enhanced functionality in the longer term and new demonstrators such as the definition of an advanced Battle Management Command and Control Demonstrator (BMC^2D). It is envisaged that projects in this area will be of significant relevance to a future BMC^2D but that they will not necessarily be directly linked to a functional theme such as Situation Assessment. They could, for example, be relatively small and exploratory stand-alone projects. Projects of longer term interest will be included as long they have potential application relevance and can be justified.

2.4.3 Central Support

Advice from those who have been involved in managing other large research programmes suggests that the allocation to these central support projects should be about 10% of total budget.

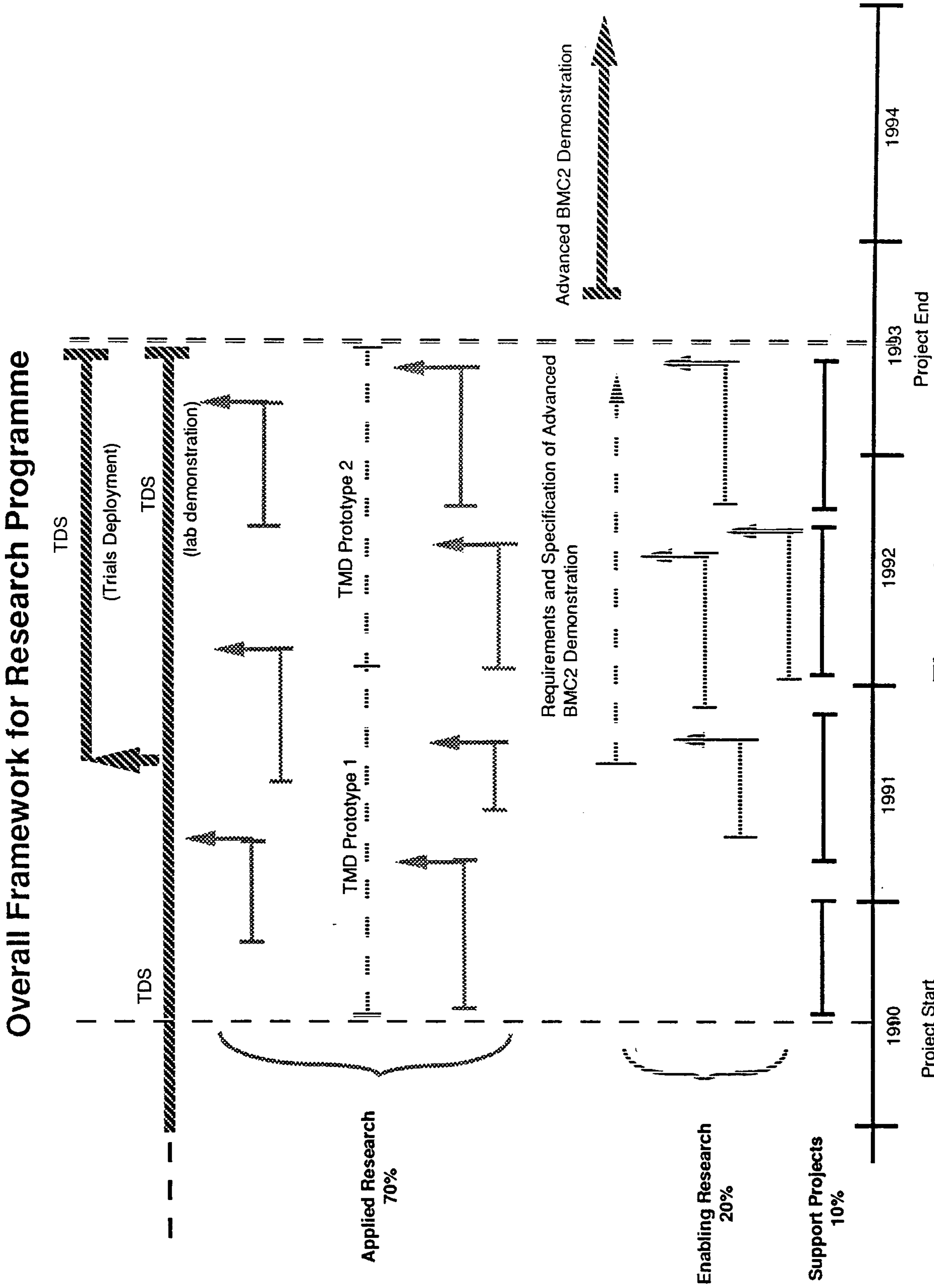

Overall Framework for Research Programme
TDS
(Trials Deployment)
TDS
(lab demonstration)
TDS
TMD Prototype 1
TMD Prototype 2
Requirements and Specification of Advanced BMC2 Demonstration
Advanced BMC2 Demonstration
Applied Research 70%
Enabling Research 20%
Support Projects 10%
1990
Project Start
1991
1992
1993
Project End
1994

Figure 1

2.4.4 Balance

Emphasis should be placed upon on applications work rather than longer term enabling research. There are two main arguments for this. Firstly, a good deal of earlier ARE exploratory work is now ready to be engineered for practical evaluation. Making sure that this happens effectively is crucial for continuing support of the technology. Secondly, the limits of what can be done with existing techniques need to be fully investigated and clearly understood.

However, it is appreciated that to achieve significant strides in functional improvement, radical new approaches will be needed. It is therefore essential that balance is maintained through a significant amount of resource for enabling research to ensure continuity and development of C^2 capabilities beyond the time horizon of the current demonstrators.

2.5 Balance between technologies

Section 2.4 discussed the balance of effort in the overall programme in relation to application and timescale dimensions. This section explores the desired distribution of research effort across the six technology streams identified. It combines the results of the evaluation of streams and sub-topics, reported in Part B, and the feedback received from the ARE and the SDIO. As such it represents input to the process of generating and evaluating the final set of SANDERLING projects.

It does not follow that the final set of projects in sections 6&7 contains a technology balance exactly as set out below. Rather, it shows that the balance agreed in this dimension was used as guidance in selecting and defining projects and has been reflected indirectly in the balance of projects and their content.

- Hardware Architectures — Low

  (paradigms are the priority)

- Real-time and systems — Low

  (system engineering and distributed AI are the priority)

- Knowledge Representation and Manipulation — High

  (uncertainty, temporal reasoning and planning are the priorities)

- Human-Computer Interaction (HCI) — Medium

  (physical interface, user support and design methods and tools are a priority)

- Database/Knowledge Base Interaction — Low

  (dynamic databases and coupling are priorities)

- Development Methods — Medium

  (Validation and verification, machine learning, specification and maintenance are priorities)

Part B gives a more detailed breakdown of priorities within each stream.

2.6 Project and Programme Evaluation

Section 6 of this report details the process and factors that were used to evaluate the proposed projects and to recommend the resulting programme. In summary, in addition to the factors and balance discussed in sections 2.2 to 2.4 above, the following criteria were used to evaluate each project and to support a recommendation to include the project in a short list and the overall programme.

- **Criticality:** how critical is this project to the achievement of the programme objectives ?
- **Risk / timescales:** how large are the technical risks or the timescales required to achieve significant progress ?
- **Defined deliverables:** priority is where a project has clearly defined short term benefits;
- **Special Research:** priority is where the research is very specific to Naval/TMD C^2 and is very unlikely to be carried out elsewhere;
- **Special Capability:** priority is where the UK is known to have a technical lead in a research field;
- **Result/Costs:** priority is for projects that maximise the result/cost ratio - eg. by building on existing work or utilising available hardware resource.

Projects are ordered to form an options list consisting of two types of projects. One short listed set (Type A) will fall within the target budget of £7m. The other set (Type B) will be within an additional £7m.

In addition, a support project to provide independent monitoring and evaluation of the programme as it proceeds should be included in order to measure success and help manage future plans.

3 FORMULATION OF PROJECTS AND PROGRAMME

3.1 Method Used

An analysis by the SANDERLING team in the earlier phases of the study (Part A Section 3) generated a set of six Technology Streams and two supporting Naval and TMD Application Streams. These were broadly similar to those originally conceived by ARE and the SDIO and were: Hardware and Architectures; Real-Time and Systems Engineering; HCI; Knowledge Representation and Manipulation; Database/ Knowledgebase Interaction and Development Methods. Each stream was divided into a number of sub-topics. The priority of each sub-topic was then evaluated and a number of technically focussed research projects were generated to explore issues in each of the sub-topics (see Part B Section 3 on evaluation).

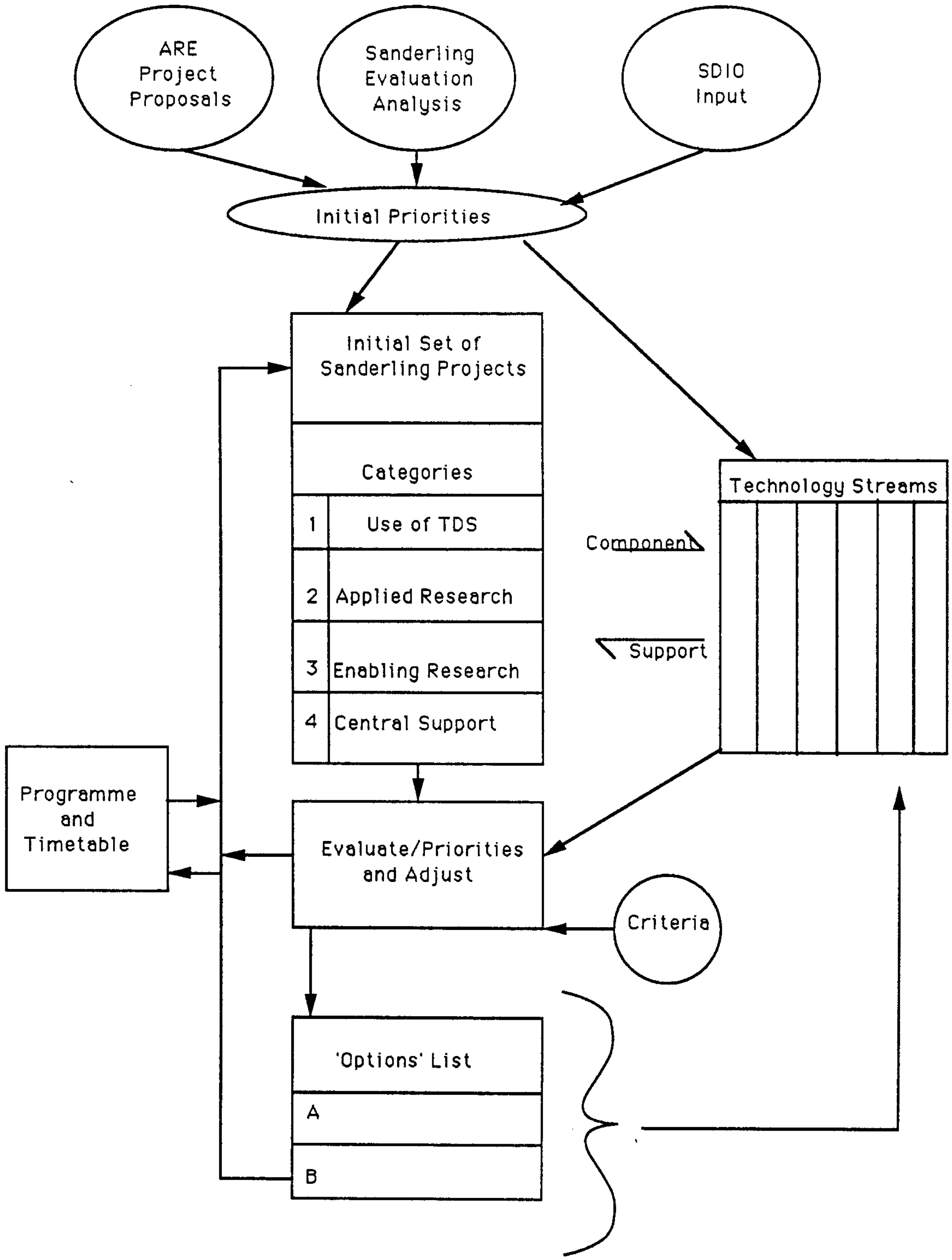
The subsequent process by which the final set of SANDERLING research projects has been generated and then evaluated to form the recommended programme is shown in Figure 2. Feedback from ARE and the SDIO on the set of research projects and sub-topic priorities was combined with an outline list of proposed research projects from ARE (Byrne 1990). This input resulted in an initial set of SANDERLING Projects (SPs) that were grouped into distinct categories. These categories changed the major focus of the projects from technology to applications and functions. The categorisation is explained in section 3.2. Each research project is given a unique SP number for ease of reference.

Following categorisation, a top-level description for each project was generated. These descriptions were expanded and refined by:

- inviting technical inputs suitable to the project goals from each of the technology streams;
- combining and rationalising these technology 'components' to form a project proposal that could be estimated.

Further refinement of the projects took place as each project was evaluated and relationships and dependencies emerged when the programme as a whole was composed.

The total number of projects was then reviewed with the SDIO and ARE and re-adjusted as part of an overall three year programme that was within the given resource priorities and constraints. The resulting 'options' list of projects was divided into two types. Type A were those projects recommended and contained within the current budgetary plans. Type B were the remaining projects. Programme timetables, dependencies and resource distribution were then made for the Type A projects and, where appropriate, their description was extended.



Process for Derivation of Sanderling
Research Project and Programme
Figure 2

3.2 Categorisation of SANDERLING Projects (SP)

The proposed SANDERLING projects were categorised as follows:

Cat	Description	Primary Domain	Sub-category
1.	TDS Support	1.Naval	1. TDS Support
2.	Applied Research	1.Naval	1. TDP 2. Lab/TDS Enhance 3. Use Lab Demo 4. Stand-alone Prototypes
		2.TMD	1. Lab Enhance 2. Use Lab Prototypes 3. Stand-alone Prototypes
3.	Enabling Research	1.TMD & Naval	1. Adv Prototypes 2. Tech Projects
4.	Central Support	1.TMD & Naval	1. Projects

A table categorising all proposed SANDERLING projects is given in Annex C1 and a detailed description of each project is at Annex C2.

The categorisation was made prior to the decision not to proceed with the TMD Demonstrator (TMDD) Phase 1. For the sake of clarity, the previous numbering system has been retained and new projects have been added to the list. Old projects that are no longer appropriate will continue to appear in Annex C1 tables, but will not be detailed in Annex C2.

The sub-categories are defined as follows:

Cat 1.1.1 TDS Support. This covers work that is in direct short term support of the sea going trials of the TDS.

Cat 2.1.1 TDP (Technology Demonstrator Programme). This category of projects provides indirect support to the TDS.

Cat 2.1.2 Lab/TDS Enhance. This covers projects that develop and enhance the TDS or other prototypes already under development.

Cat 2.1.3 Use Lab Demo. This category includes projects that specifically make use of prototypes and demonstrators to carry out experiments.

Cat 2.1.4 Stand-alone Prototypes. These are projects that involve the creation of new prototypes that are not directly integrated with other existing or planned demos or prototypes.

Cat 2.2.1 Lab Enhance. This covered projects that develop and enhance the TMDD (TMD Demonstrator). The category is no longer appropriate and detail on projects in this category will not be included.

Cat 2.2.2 Use Lab Prototypes. This category previously covered projects that specifically made use of the TMDD to carry out experiments. They will now be based on a development methods prototype defined under Cat 2.2.3

Cat 2.2.3 Stand-alone Prototypes. These are projects that involve the creation of prototypes that are not directly integrated with a major demonstrator.

Cat 3.1.1 Advanced Prototypes. These are enabling research projects that specifically aim at the generation of new prototypes in both Naval and TMD domains.

Cat 3.1.2 Technology Projects. This category includes all other longer term enabling research not included in 3.1.1.

Cat 4.1.1 Central Support Projects. These are projects that span a number of areas gathered together and provide support or long term focus for the programme.

4. RESEARCH PROJECTS

This section summarises the proposed research projects within each of the categories defined in section 3. For each category, the objectives, the main research issues, the projects and project rationale are summarised. Annex C1 and C2 provide supporting documentation: C1 gives a summary of all SANDERLING project costs and timescales, C2 gives a full description of each project including objectives, technical content, deliverables, costs and resources required.

4.1 Category 1 : TDS Support

4.1.1 Naval

4.1.1.1 Objectives

The objectives of the SANDERLING projects in Category 1: TDS Support are to provide short-term support to the TDS installation which will shortly be undergoing trials at sea.

4.1.1.2 Research Issues

The research issues to be addressed by Category 1 SANDERLING projects are as follows:

- to investigate the feasibility of enhancing the TDS to cope with more complex scenarios;
- to investigate techniques for optimising rule-based KBS for performance and demonstrating their effectiveness using the TDS;
- to investigate the development of training material for the users of knowledge based C^2 systems, using the TDS as an examples.

4.1.1.3 Research Projects

The SANDERLING projects included within Category 1 are as follows:

SP 1.1.1 Investigate the operational scalability of the TDS

This project will use the performance and competence metrics being developed under SP2.1.1.2 (Derive KBS performance and competence metrics for the TDS evaluation programme) in order to determine the operational scalability of the existing solution to the data fusion problem. At present there is no practical basis for defining the performance envelope of the TDS Version 1 Phase 3 system (e.g. graphs of the number of objects/tracks against the time taken to produce each update to the tactical picture display) or for predicting and testing the implications of varying scenario size and complexity. The project will determine the current limits of performance of the TDS Version 1 Phase 3 in terms of the number of tracks and objects it can process correctly in real-time, propose and implement alterations to the hardware and software of TDS Version 1 Phase 3 for extending its performance envelope to deal with scenarios of varying size and complexity, and analyse the scalability aspects of the sea trials conducted with the TDS.

SP 1.1.2 Enhance TDS Performance by Knowledge Base Optimisation

This project will increase the operating speed of the TDS Version 1 Phase 3 by focussing attention on the efficiency of the KBS implementation. Account will be taken of the previous and existing work carried out at ARE by John Daniel (Daniel 1989). The primary concern will be increasing the speed of operation, while retaining functional levels of performance (i.e. accuracy and completeness of output) using the current serially based implementation as used in TDS Version 1 Phase 3 as a baseline from which to conduct the project. There are a range of techniques which are available to optimise KBS design for performance. Each of these will be investigated on a small subset of the KBS component of the TDS Version 1 Phase 3, and the most promising options will be selected for a more detailed implementation.

SP 1.1.3 Development of Training for the TDS

This project will prepare the necessary lecture notes, visual aids, tests of competence, and computer based training material for training prospective users and operators of the TDS (users are defined as the officers on board a ship who use the output of the TDS to make high-level decisions on the running of the ship, and operators are defined as those men who interact directly with the TDS, passing on the output as appropriate to the users). The main objectives of this project are: to produce comprehensive training material for prospective users and operators of the TDS Version 1 Phase 3 as is to be used in the forthcoming shore based and sea trials, to run training courses at ARE, in order to ensure that students are trained as quickly as possible to a sufficient level of understanding of the TDS that they are able to intelligently report on the TDS and contribute to its development, and to evaluate and improve the quality of the training material based on student reaction, and in light of how training can be improved to resolve and anticipate user and operator problems recorded during the sea trials of the TDS.

4.1.1.4 Project Rationale

The SANDERLING projects outlined in section 4.1.1.3 directly address the objective identified in section 4.1.1.1, that of supporting the sea-going trials of the TDS, by working towards the enhancement of the performance of the existing prototype thereby broadening its range of operational applicability, and by providing material to for the training of TDS users. Although the evaluation of the TDS has yet to be carried out it is a reasonable assumption that further gains can be identified by activities such as this and as such the projects listed have a significant role to play in the TDS trials activity.

4.2 Category 2 : Applied Research

4.2.1 Naval

4.2.1.1 Objectives

The objectives of the research proposed within Category 2.1 fall into three main areas:

- to evaluate and assess the performance of the existing TDS. This includes: evaluation of the TDS KBS with respect to performance and competence, to validate the existing TDS knowledge base and to evaluate a number of aspects of the HCI of the existing TDS prototype;

- to develop techniques and tools to support the continued operation of the existing TDS therefore ensuring sufficient trials availability to allow a full and thorough user evaluation. This includes: maintenance of an operational KBS and development of a methodology for knowledge acquisition in problem domains with a spatial and/or temporal component;

- To enhance the functionality of the TDS by focussed research in a number of key technical areas including: enhancement of the Situation Assessment and resource allocation prototype currently under development, development of explanation in Situation Assessment systems and KBS-based HCI for C^2 systems.

4.2.1.2 Research Issues

The research issues to be addressed by Category 2.1 SANDERLING projects are as follows (grouped according to the three objectives identified in 4.2.1.1):

(1) To develop metrics for evaluating KBS performance and competence and assess their effectiveness by applying them to the TDS.

- to evaluate the impact of the TDS on the Naval operating environment;

- to evaluate the effect of operator interaction with the TDS;

- to devise techniques to support validation of the interface between a user and a KBS in complex domains and to evaluate those techniques by applying them to the TDS;

- To evaluate the performance of the TDS as a data fusion system

(2) To investigate efficient database and knowledge base coupling techniques within the TDS environment.

- To develop methods and tools for task analysis in the C^2 domain;

- to develop techniques and tools to optimise the design of HCI for Tactical Picture Displays.

- to develop techniques and tools to support the maintenance of an operational KBS and to investigate their efficacy with respect to the TDS.

- to develop a methodology for knowledge acquisition in domains with a spatial and/ or temporal component, and to evaluate its effectiveness with respect to the enhanced TDS.

- to develop techniques and tools for a posteriori validation of KBS and evaluate their effectiveness by applying them to the TDS.

(3) To determine how the Situation Assessment Prototype and Resource Allocation Prototype which will be developed as part of ARE's current programme can be enhanced by incorporating more advanced knowledge representation and manipulation techniques, such as temporal and spatial reasoning.

- to determine the feasibility of porting elements of the TDS to a parallel architecture;

- to investigate the HCI issues involved in developing Situation Assessment and Resource Allocation prototypes;

- to investigate the use of KBS techniques in the HCI of advanced C2 systems;

- to investigate the use of KBS for amphibious operations support.

4.2.1.3 Research Projects

The SANDERLING projects included within Category 2.1 are as follows:

SP 2.1.1.1 Database/Knowledgebase Interfacing Techniques for Application to the TDS

The TDS will be required to interface to a number of databases for access to both geographic and encyclopaedic data when in operational use. The speed of access to that data could place a limit on the performance of the system as a whole. In the longer term, this may be overcome by the use of closely coupled database / knowledge bases, but in the short - medium term the most pragmatic approach involves treating the database and KBS components as discrete, loosely coupled entities.

This project is concerned with establishing the most efficient techniques for coupling databases and KBS. It will involve the creation of a model of the performance constraints faced by different coupling techniques. The investigation will then consider the extent to which it is possible to optimise the coupling process with regard to the inference and data requirements of the TDS.

SP 2.1.1.2 KBS Performance and Competence Metrics for the TDS Evaluation Programme

In order to conduct a meaningful evaluation of the performance and competence of the KBS component of the TDS it is necessary to first establish a sound set of metrics. These will need to encompass many aspects of system behaviour, including performance, competence and user interaction. This project will investigate the requirements of the trials programme and derive an appropriate set of metrics for the evaluation of the TDS as a non-interactive data fusion system. It will then apply them to the TDS. The evaluation of the TDS as an interactive system is addressed in projects SP2.1.1.3, SP2.1.1.6 and SP2.1.1.7.

SP 2.1.1.3 Evaluation of the Impact of the TDS on the Operating Environment

This project will investigate the impact of the TDS on the overall C2 system.

Although SP2.1.1.2 will evaluate the performance and competence of TDS Version 1 from a KBS perspective there are still a number of other evaluation activities which need to be carried out in order to fully assess the success of TDS Version 1 as a component of an overall C2 system. This project aims to satisfy some of those requirements related to the impact of the TDS on the operating environment.

The project addresses ARE objective EXPRO 6, and in particular the following aspects :

- task, job and organisational effects;
- effect on operator attitudes;
- effect on workload of operations room personnel.

This project will also generate recommendations for assessing the impact of the TDS on manning levels and training requirements.

SP 2.1.1.4 Develop Design Methods and Tools for Task Analysis

This project will develop design methods and tools for task analysis, goal analysis and allocation of function for specifying the user requirement from the TDS. The user requirement will be considered in terms of operational, organizational, and training issues. The main objectives of this project is are to identify methods and tools for task analysis of C^2 applications, and to analyse the SAP-1 using these techniques and to produce prototype implementations incorporating some of the recommendations.

SP 2.1.1.5 Optimisation of HCI Design for Tactical Picture Displays

This project will continue the work done to date at ARE on the development of tactical picture displays. It will use and extend the software already in existence to conduct experiments aimed at producing an optimal set of symbols and picture display parameters for the data fusion and Situation Assessment modules of the TDS. The objectives of this project are therefore: to set up an environment in which human factors experiments based on the tactical picture display component of the TDS Version 1 Phase 3 and the Situation Assessment Prototype (SAP) can be conducted, to assess and quantify the quality of the existing tactical picture display for the data fusion and Situation Assessment modules of the TDS through a set of observer experiments, to produce a set of criteria for evaluating the quality of a particular tactical picture display, and to modify the existing tactical picture display software based on the results of the observer experiments.

SP 2.1.1.6 Evaluation of the effects of Operator Interaction with the TDS

This project will analyse the human components effects on performance of the TDS system as a whole (issues include whether the tactical picture can be improved by user modification, and the identification of the manual interactions made in assisting TDS performance), and identify potential knowledge based enhancements and necessarily human contributions to the data fusion process. It will explore the nature, content and effect of all forms of operator interaction (both actual and desired) with the TDS Version 1 Phase 3. It will run a series of experiments aimed at identifying those forms of interaction which take place consistently across a number of operators, as well as discovering which forms of interaction have not been adequately addressed. It will determine the effects of such interactions upon data fusion performance and identify the nature of the human contribution. The necessary roles of human and knowledge base components in the data fusion process will be clarified and refined where appropriate.

SP 2.1.1.7 Validation of the TDS HCI

The HCI of the TDS needs to be assessed at three levels, first in terms of presentation (sensory-motor) which will include operators' and users' views on colour, shapes, input devices, window content and format of information, second in terms of the information level which refers to the way in which the operators and users use windows menus etc., and finally in terms of the understanding level which refers to the extent to which the operator or user has an overall appreciation of and understands the system. This project is specifically aimed at meeting these objectives, together with an assessment of the whole process of HCI specification, design and implementation, the results of which can be used to validate the HCI of the TDS and specify future HCI requirements for the procurement of C^2 systems.

The project will specify a set of criteria, metrics, and appropriate experiments for assessing the HCI component of the TDS Version 1 Phase 3. It will run these experiments using the land based TDS using a number of observers to obtain a consensus of opinion. Based on the results of these experiments, a further set of more focussed observer experiments will then be conducted as part of the sea trials of the TDS.

SP 2.1.1.8 To Evaluate the TDS as a Data Fusion System

This project will evaluate the TDS as an interactive data fusion system, performing in an operational environment. It isolates the performance of the TDS from considerations of peripheral issues such as sensor capabilities, and includes a comparison of the man-machine complex with less automated approaches.

The project addresses ARE EXPRO 1, the components of which are :

- to assess the quality of tactical picture which can be generated by the TDS, working in conjunction with the operator in an operational context;
- to provide an objective measure of the performance and competence of the TDS which can be assessed independently of peripheral factors such as sensor performance;
- to provide an initial indication of the characteristics and capabilities of the TDS relative to more conventional systems.

SP 2.1.2.1 Enhanced Situation Assessment Prototype

The project is concerned with the extension of the Situation Assessment prototype currently being procured to support its use in an operational context and to rationalise the representation schemes as a basis for further work in resource allocation and planning.

The project aims to develop a new Situation Assessment prototype addressing: the generation and manipulation of multiple uncertain possible interpretations of the tactical picture; robust portable representation primitives for Situation Assessment, resource allocation and Planning and storage mechanisms for real-time manipulation of the above.

SP 2.1.2.2 Enhanced Resource Allocation Prototype

This project is concerned with enhancements to the Resource Allocation Prototypes to support their continued development as decision support tools and the refinement and rationalisation of their internal workings.

The objectives include: the integration of representation systems developed for SAP-2 into resource allocation prototypes; the re-evaluation of the performance of resource allocation (RA) prototypes and the modification of their architecture or updating of their knowledge bases as appropriate (e.g. for force-level RA); the design and implementation of an integrated decision support system based around reactive and background RA processes co-ordinated through the main battle plan.

SP 2.1.2.3 Enhanced TDS Performance by Concurrent Processing

This project will continue the work done to date at ARE on examining the potential for exploiting concurrent processing within the TDS Version 1. Speed of operation has been identified as a critical factor in determining the TDS system's acceptance as a valid solution to the C^2 problem. Recent advances in hardware, together with appropriate software programming environments, mean that concurrent processing is a much more readily accessible technology. Therefore, this project will continue the work on examining rule bases in specific knowledge sources for static and dynamic parallelism together with assessing the potential for the use of fine and coarse grained parallel solutions and architectures for all aspects of the data fusion module. It will run a series of experiments to show increases in the operational speed of the the TDS Version 1 Phase 3 through prototype implementations of techniques on a concurrent computing system. Experimental results will have to indicate that the concurrent processing prototypes will not behave adversely if implemented on the wider scale of scenario expected within the operational context of the TDS.

SP 2.1.2.4 HCI for Situation Assessment and Resource Allocation

This project will investigate the processes underlying human Situation Assessment and resource allocation and produce a validated model that will be suitable for determining how best to provide computer based assistance and HCI facilities for the Situation Assessment and resource allocation functions. An HCI suitable for inclusion in current and future Situation Assessment and resource allocation research projects will be built.

While it is possible to design a KBS system to perform Situation Assessment and resource allocation, the key factor in the model construction will be to derive what the human operators and users will require from any computer based support tool (i.e. user oriented design to some extent) so that they can improve on current levels of performance (e.g. in terms of speed or accuracy of decision making). Situation assessment and resource allocation are both being tackled in this project because of the difficulty in isolating them as completely independent functions. If this project shows that this is the case to a greater extent than already assumed, then there may be implications for the overall system architecture.

SP 2.1.3.1 Development of Techniques for KBS Maintenance

In order to ensure that the TDS Version 1 can be kept operational for a sufficiently long period to enable evaluation and trials to be effectively carried out, provision will need to be made to support maintenance of the sea-going system.

This project will investigate extensions to the KBS life cycle model and will develop prototype software tools to support the maintenance of knowledge based systems for C^2.

The objectives of this project are to:

- develop techniques and tools to support the maintenance of TDS Version 1 during its evaluation;

- develop foundation for a more structured approach to the maintenance of further versions of the TDS and TMD.

SP 2.1.3.2 Investigation of Techniques for Knowledge Acquisition

In order to support the development of future enhancements of the TDS there will be a need to carry out knowledge acquisition in domains with a temporal or a spatial component.

The knowledge acquisition techniques which have been developed to date, eg. repertory grids, have tended to concentrate on the declarative elements of knowledge, ie. objects, relationships etc.. As such they fail to address many aspects of procedural knowledge and are inadequate to extract and represent the concepts involved in spatial and temporal knowledge. This project will identify knowledge acquisition methodologies and tools for applications with a spatial and/or temporal component. This may involve extending or adapting existing techniques, and evaluating their potential using further developments of the TDS.

The objectives of this project are:

- to develop a methodology for knowledge acquisition for problem domains with a spatial and temporal components;

- to evaluate the effectiveness of the methodology with respect to further developments of the TDS and related projects, including SAP, RAP and the TMD programme.

SP 2.1.3.3 Development of Methods and Tools for the *A Posteriori* Validation of KBS

In order to deploy KBS with a sufficient degree of confidence it will be necessary to carry out a validation process upon the knowledge base and to evaluate the significance of the results of that validation process.

This project is concerned with the development and assessment of techniques for the *a posteriori* validation of real-time KBS, using the TDS Version 1 knowledge base as a testbed. *A posteriori* validation refers to validation which is carried out after the system development process has been completed. This is recognised as a fundamentally difficult task, since the performance of the final system cannot always be related back to a coherent expert model. However, some progress has been made in the area, eg. in Esprit project VALID, and this project should build on that work.

The objectives of this project are:

- to devise techniques for the *a posteriori* validation of KBS;

- to use those techniques to validate aspects of the TDS Version 1 knowledge base;

- to define the limits of *a posteriori* validation of KBS.

Further work in SANDERLING project SP2.2.2.2 extends the range of techniques to cover *a priori* validation, ie.. validation which takes place during the KBS development process.

SP 2.1.3.4 Exploration of Techniques for Explanation in Situation Assessment Systems.

The provision and use of explanation facilities is acknowledged as an essential pre-requisite for most expert systems. It is often given insufficient consideration in the development cycle, system developers having less need for such high-level assistance. This project will extend the work done to date at ARE on the development of a graphical explanation facility for the data fusion module of the TDS, specifically to produce explanation facilities for use with the situation assessment module of the TDS. The work will include an analysis of the explanation requirements of operators, and an investigation of alternative methods for the display of explanations, with special consideration given to the representation and manipulation of uncertainty.

It will also ensure that the proposed explanation facilities integrate with the other work on the development of the HCI for the TDS system and conduct a series of human factors experiments designed to elicit reactions to various methods of explanation from prospective users of the situation assessment module.

SP 2.1.4.1 Exploration of Adaptive Interfaces for C^2 systems.

This project will investigate the opportunities for the design and prototype implementation of a KBS to facilitate and improve the quality of the HCI component of the TDS system. The aim is to evaluate the potential for enhancing the MMI of C^2 systems through the use of KBS : specifically to investigate the design and application of adaptive interfaces in KBS-based C^2 systems. It will do this through the use of the HCI component of the TDS Version 1 Phase 3 as a vehicle for experimentation and prototype implementation of an adaptive interface. The project will first determine a set of operating conditions which justify the need for an adaptive interface in a C^2 system, then produce profiles of the types of operators and users of the TDS and evaluate the suitability of each of the constituents of the HCI of the TDS Version 1 Phase 3 to the inclusion of an "adaptive" component. It will use this to construct a prototype a knowledge based system for implementing an adaptive element of the HCI component of the TDS Version 1 Phase 3, which will then be used in a small-scale observer experiment designed to assess the added value obtained from the prototype adaptive interface.

SP 2.1.4.2 KBS for Amphibious Operations Support

This project will develop an integrated system of co-operating KBS planners which assist the amphibious command in preparing ship stowage and disembarkation plans. In addition, a KBS-based prototype is to be developed which will support land and ship based assets in defending an Area of Operations. The overall planning of an amphibious assault co-ordinates the different plan processes necessary.

4.2.1.4 Project Rationale

In section 4.2.1.1 the principal objectives of the Category 2.1 SANDERLING projects were identified. Having now considered the individual projects, it is useful to consider how they contribute to those overall objectives. A summary of contribution to objectives is given below.

- To evaluate and assess the performance of the existing TDS. This is addressed in the following projects:

  SP2.1.1.2 KBS performance and competence metrics for the TDS evaluation programme
  SP2.1.1.3 Evaluation of the impact of the TDS on the operating environment
  SP2.1.1.7 Validation of the TDS HCI
  SP2.1.1.8 To Evaluate the TDS as a Data Fusion System
  SP2.1.3.3 Development of methods and tools for the a posteriori validation of knowledge based systems

- To develop techniques and tools to support the continued operation of the existing TDS therefore ensuring sufficient trials availability to allow a full and thorough user evaluation to be possible. This is addressed in the following projects:

  SP2.1.1.1 Database/Knowledgebase interfacing techniques for application to the TDS
  SP2.1.1.4 Develop design methods and tools for task analysis
  SP2.1.1.5 Optimisation of HCI design for tactical picture displays
  SP2.1.1.6 Evaluation of the effects of operator interaction with C^2 systems
  SP2.1.3.1 Development of techniques for KBS maintenance
  SP2.1.3.2 Investigation of techniques for knowledge acquisition

- To enhance the functionality of the TDS by focussed research in a number of key technical areas. This addressed in the following projects:

  SP2.1.2.1 Enhanced situation assessment prototype
  SP2.1.2.2 Enhanced resource allocation prototype
  SP2.1.2.3 Enhanced TDS performance by concurrent processing
  SP2.1.2.4 HCI for situation assessment and resource allocation
  SP2.1.3.4 Exploration of techniques for explanation in situation assessment Systems
  SP2.1.4.1 Exploration of Adaptive Interfaces for C^2 systems
  SP2.1.4.2 KBS for amphibious operations support

4.2.2 TMD

4.2.2.1 Objectives

Stand-alone prototypes will be used to investigate TMD application functions.The objective of this line of research is to extend the work beyond data fusion into the more demanding (from an AI perspective) areas of TMD C2. Specific application-driven prototypes will act as vehicles for technology research.

A further class of objectives is aimed at utilising the applications prototypes to investigate the use of supporting software methods in the development of AI based systems.

4.4.2.2 Research Issues

The research issues addressed in the TMD experiments cover three different but related aspects:

1) The continual stretching of the boundaries of where AI technologies can support all the functions in an SDI TMD BM/CCI system. Data fusion is seen only as the first function along the chain of situation assessment, resource allocation and reactive planning

2) The integration of technologies into an optimised system. It is recognised that for the long term optimal solution to the support of the BM/CCI function, the implementation will be a hybrid of algorithmic, AI, novel and conventional information systems approaches. Candidates for any function must be compared, selected and a target system put together by integration into an optimised whole.

3) The TMD applications must be able to perform in one of the most constrained and stressed situations. Many implementors would prefer that the human was not involved. This is clearly politically unacceptable, even though a system could be developed that performed without supervision. The man must be in control of the machine and of the situation. For these reasons the HCI aspects play a prominent part in the research.

4.2.2.3 Research Projects

The research projects within the TMD environment which will be investigated are divided into three categories, as detailed below.

Category 2.2.1: Projects that use the TMDD Phase 1 as a host

The projects in this category were planned to use the TMD Demonstrator as a host. However, because of the decision not to proceed with the TMDD these projects have now been withdrawn. The titles of these projects were.

SP 2.2.1.1 The evaluation and assessment of the TMD Demonstrator

SP 2.2.1.2 Integrated Data Fusion using the TMD Demonstrator

SP 2.2.1.3 Incorporation of situation assessment and resource allocation into TMD Demonstrator

SP 2.2.1.4 Integration of Discrimination into the TMD Demonstrator

Category 2.2.2: projects that use TMD prototypes to investigate supporting development methods

SP 2.2.2.1 The Specification of KBS for Command and Control Applications

Specification of KBS is currently a vague and unsatisfactory process, often being a successive iteration process whereby the developers' and users' expectations gradually reach a point of equilibrium.

This project is concerned with investigating the specification of a real-time KBS in the C^2 domain, by using the Development Methods Prototype (SP2.2.3.4) as a test vehicle. Particular consideration will be given to the role of a KBS life-cycle model in the specification process and the specification of speed, accuracy and performance requirements. In addition consideration will be given to the production of test specifications for KBS applications to C^2.

This project is not intended to address the feasibility of using formal methods to specify a KBS, this is addressed by SP3.1.2.3.

The objectives of this project are:

- to establish techniques for the specification of KBS in the C^2 domain. in particular the specification of speed, accuracy and performance requirements;
- to establish techniques for the production of test specifications for KBS applications to C^2 applications;
- to provide input to MOD/DOD guidelines for KBS procurement.

SP 2.2.2.2 Verification and Validation of 'Safety Critical' KBS

This project will investigate techniques for the *a priori* validation of C2 applications of KBS and explore their effectiveness in relation to the Development Methods Prototype (SP2.2.3.4). The term *a priori* validation is used to refer to validation which is carried out during the development process of the KBS.

This project follows on from SP2.2.2.1, since specification techniques will be a necessary prerequisite:

- To identify and devise techniques which can be used to support the *a priori* validation of C2 applications of KBS;
- To validate aspects of the Development Methods Prototype using the techniques identified.

SP 2.2.2.3 Investigation into the Robustness of KBS architectures

This project will explore the robustness of the KBS architectures using the Development Methods Prototype (SP2.2.3.4) and recommend the best means of providing robust KBS.

The work will involve experimenting with the Development Methods Prototype (DMP) to identify the weak areas of the system. Software trials will be undertaken to investigate ways around these problem areas and from these trials a set of generic design principals and specific implementation recommendations will be made.

SP 2.2.2.4 Operational Adaptivity of Knowledge Bases

The objective of this project is to investigate the adaptability of an operationally deployed system to changes "in the field". It is envisaged that, as an engagement develops, an adversary could begin to pre-guess one's own KBS-based tactical decisions. A commander may feel it to be tactically beneficial to replace some doctrinal or encyclopedic rule base with new rules "made on the fly". Such a change could be as catastrophic as the alternative of being predictable to the enemy. The project will investigate ways that rules could be changed by the user so that they are fully and completely composed and specified through the HCI together with the supporting validation.

The research will investigate the feasibility of using machine learning techniques to enable in situ maintenance of KBS. It will also consider the tools necessary to support the development of an alternative rule set.

A further part of the research will also consider the implication of such system adaptivity for validation and verification.

SP 2.2.2.5 Integrating Knowledge Representations

The objective of this experiment is to provide an enabling technology for developments beyond the three year timescale of SANDERLING's proposed projects. The capability to build and extend systems and interface them successfully will rest on the availability of consistent, efficient and powerful representations for the fundamental components of reasoning in these domains: uncertain, temporal, spatial and modal knowledge. Specifically, the aim is to provide a well-founded set of knowledge representation formalisms drawn from the results of the many studies and prototyping exercises taking place during the programme.

SP 2.2.2.6 Development of KBS not based on 'Expert' Knowledge

In a number of circumstances it may be necessary to consider the development of a knowledge based system for a problem domain for which there is only limited human expertise, such as the TMD data fusion problem. In such cases a number of possible approaches exist including extrapolation from existing expertise from a similar problem, model-based reasoning or machine learning.

The objective of this project is to devise techniques which could be used for knowledge acquisition and validation in such application domains.

SP 2.2.2.7 Real-Time Integrated Databases

This experiment is an investigation of issues surrounding the integration of databases with knowledge bases for TMD applications. It takes as an assumption the probability that such databases will be object-oriented and examines the implications of such data structures on database models. It is fundamental that any database will have to be capable of interacting in real-time with the threat assessment and resource allocation systems performing automated battle management. The other aspect of this project is therefore a study into methods of providing such performance through an analysis of domain structure and interaction requirements.

Category 2.2.3: Projects that will make use of stand alone prototypes

These projects extend the horizon of the use of AI techniques to functions for which it is best to perform the research on stand alone prototypes.

SP 2.2.3.1 Adaptive Preferential Defence

The object of the experiment is to investigate and show the use of HCI and AI techniques, working together, in the time-constrained resource allocation application. Furthermore, this aspect of the TMD scenario has close parallels to the Naval C2 scenario.

Other terms related to the Adapted Preferential Defence function, and used elsewhere in the literature, include Reactive Resource Allocation, Re-planning and modifications to the Course of Action, Target Evaluation and Weapon Assignment (TEWA) policy.

The key topic in this project is the HCI. The experimental components should explore the monitoring / supervisory role and extent to which an interactive environment can be achieved:

- where the system is primarily automatic / algorithmic ;
- where the system has AI elements.

Related research activities investigate the relevant paradigms, knowledge acquisition and real-time system design topics.

There is the potential for a number of experiments looking at specific decisions. Comparison of results would be on speed and effectiveness of decisions in a time-constrained situation. The experimental system will draw on experience gained from the ARE RAP-1 and RRASSL (Reactive resource allocation at Single Ship Level) prototypes.

SP 2.2.3.2 Sensor Management

The object of this project is to show the use of HCI and AI techniques, working together, in an application which is driven by spatial representation and display.

Particular problems which are addressed in this project include those associated with:

- the storage and real-time manipulation of a large amount of spatial information;

- the representation of uncertainty in spatial data;
- the coupling of the KB and database;
- the display of uncertainty and explanation in a spatial representation;
- the detection of events to initiate a re-plan.

This aspect of the TMD scenario has close parallels with the Naval C2 scenario. The project is considered here under two application headings although the approach to coverage and management is similar for both :

- Sensors

In the Electronic Warfare environment, with the use of jammers and other electronic countermeasures, there is the need to control adaptively the coverage and performance of ground/shipborne radars to achieve optimum coverage of the battle space. Sensors should be able to achieve their intended contribution to the overall task rather than just achieve some coverage. A series of experiments can be developed to investigate sensor management and coverage planning and re-planning.

- Weapons

Good knowledge is required of the instantaneous state of own assets to be defended and of the current weapon coverage and state to optimise the coverage to achieve the overall defence objective. The algorithms must consider the number of remaining assets in a defined class, their net value and ability to achieve their objective as well as priority to the allies. The weapon primary coverage area could then be modified and if time allows the firing unit moved.

<u>SP2.2.3.3 Intention Prediction of Intelligently Manoeuvering Objects</u>

The object of the experiment is to show how AI techniques can be used to forward predict the track of objects with known pre-programmed manoeuvre capability. The work in this experiment is equally applicable to the Naval and TMD domains.

In the TMD scenario future generations of Soviet re-entry vehicles (RVs) could have the capability to perform a simple manoeuvre either : in mid-course, during re-entry or immediately prior to impact (terminal guidance).

In the Naval domain the types of incoming missiles will vary through many classes including, anti-radiation homing, various high, very high, steep diving or low attack profiles, surface huggers and torpedoes, all with a limited selection of in-flight manoeuvre profiles. By combining intelligence information and physics with gaming theory, a KBS could be formed to assist the track prediction and IPP (Impact Point Prediction) functions. This predictor is an essential prerequisite to the subsequent threat assessment and situation assessment functions.

SP 2.2.3.4 Development Methods Prototype

The main objective of the project is to provide a focussed applications prototype to support the investigation of techniques for the specification and evaluation of KBS outlined in the Category 2.2.2 projects list. It will provide a research platform to support development methods projects whilst investigating further issues in situation assessment that will extend beyond those related to the nearer term Naval and TMD KBS projects.

The first activity in this project will be to select the application topics for research. Examples of tactical situation assessment which are potential applications for inclusion in this project are given in (Miles, 1988). These applications have a synergy between the Naval and TMD domains, however it is proposed that a TMD application is selected. Further, it is anticipated that as a result of the TDP the researchers will have an understanding of how the output of the SAP is assimilated by the operator/user and this would form the basis of a further set of rules to be incorporated in an enhanced functionality prototype.

It is suggested that the most suitable topic for this further research is to investigate reactive (dynamic) situation assessment, and in particular to investigate the real-time selection of Course of Action and to modify such a selection as a result of raid analysis.

SP 2.2.3.5 Hybrid Approach to Data Fusion

Neither a wholly symbolic, nor a wholly numeric paradigm will be capable of solving completely all of the problems associated with data fusion in a large scale, complex real-world application such as TMD. The overall goal of this research is therefore to determine the most promising paradigms for integrating symbolic and numeric techniques of data fusion, and to evaluate their likely performance in comparison to a fully AI or numeric based solution. The project will compare knowledge based and algorithmic approaches to association, correlation, discrimination and prediction with reference to performance and constraints on use. It will then identify a hybrid approach, with estimates of likely improvements in performance (speed, accuracy), reliability (fault tolerance, survivability to loss of sensor) and scalability over purely numeric or symbolic approach. This hybrid approach will be examined through construction of a prototype. The work will also study the hardware architectural implications of the methods developed, and in particular the balance required between centralised processing and control, and decentralised/distributed alternatives. The requirements for real-time performance of the method will also be identified.

4.2.2.4 Project Rationale

There are a number of themes that inform the projects, both within single categories and between them. These themes are :

- The first set relate to the use of the TMDD in developing and utilising AI/KBS assessment metrics. However with the cancellation of the TMDD the projects in category 2.2.1 have been withdrawn. Some of the research issues are addressed in stand-alone prototypes proposed in category 2.2.3.

- The second set of projects do not relate directly to a TMD application or to the activities of developing a prototype or demonstrator in a laboratory. They relate to the software systems engineering aspects of developing a system to an acceptable quality standard that can be delivered to the service customer. The projects in this category each consider a systems engineering aspect and assesses its implication on the supporting technologies.

- These projects involve prototype development. The projects consider the major application issues beyond data fusion and consider how these will act as drivers on the AI technologies. The applications have been chosen as sufficiently large in scope on a particular theme to be able to support a number of individual research topics over all the technologies. The five projects chosen each have a different emphasis. The first project stresses the HCI in a decision process that is more temporal and modal/deep than the second which stresses the HCI with a spatial problem. The third project is an exercise in uncertainty and in its display. The fourth project builds a prototype as a vehicle to support the development methods projects. The fifth investigates a combined AI and numeric approach to data fusion.

- Special effort has been made to ensure that development methods are covered in the programme. These are identified separately in category 2.2.2. This was necessary as the applications themselves did not offer a natural vehicle for carrying development methods research incorporated. Any system delivered to a military end-user must be developed under quality-controlled conditions.

All the applications projects and their accompanying technology research topics are focussed on TMD applications. However, they are equally applicable and have close synergy with Naval command and control.

4.3 Category 3: Enabling Research

This section addresses research projects looking further forward than the application-led projects are able. It combines experiments stemming from the technology streams into co-ordinated projects and includes other topics that do not fit comfortably into the application-focussed projects.

4.3.1 TMD and Naval

The projects in this subsection will address issues raised in both application domains. For convenience, the Naval domain has been chosen as a practical focus for SP3.1.1.2 because of the near-term availability of application domain prototypes and supporting material such as exercise transcripts.

4.3.1.1 Objectives

The objective of these projects is to address aspects of operational use of knowledge based decision support systems that are outside the current main concerns of the Naval and TMD programmes but which are nevertheless important to eventual successful deployment. The experiments are therefore intended to be divorced to some degree from the main TDS- and TMD-led activities.

4.3.1.2 Research Issues

The research issues chosen are:

- the use of knowledge-based decision support systems on multiple ships, and their co-ordination;

- defining the command and control system as a tool for man-based decision processes, to address aspects of "man-in-the-loop" operation as opposed to "man in supervisory control".

4.3.1.3 Research Projects

SP 3.1.1.1 Distributed Situation Assessment

The main part of the Naval Applications research programme includes the development of a situation assessment system (which is currently being tendered for) and its enhancement towards integration in a Battle Management system. This enhanced functionality is still based on single-ship operation of a knowledge based command and control decision support system. Clearly, it is as important to think of the implications of having such systems on several ships and the distribution of functions across those ships, with the concomitant enhancements this requires to the data fusion and situation assessment architectures. TMD architectures are based on distributed sensing networks and command functions too, and will therefore ultimately require these issues to be addressed.

The current data fusion demonstrator, for example, has a large part of its function devoted to the fusion of sensor data from "own ship" and that arriving from another ship via a datalink. The datalink information is assumed to be in a form similar to that being reported from "own ship's" sensors, the implication being that there will be an enormous traffic of sensor data being passed from ship to ship. This represents a problem of combinatorics in Data Fusion (Miles 1988) to which Distributed Artificial Intelligence (DAI) offers a solution. The intention within this project is to examine the practical constraints on the distribution of information and functions within a Naval task force or TMD command structure and to examine the best means of co-ordinating situation assessment between a number of platforms, on the assumption that Data Fusion takes place on each platform individually.

SP 3.1.1.2 Co-Operative Planning Aids for Command and Control

For two reasons decision aids for Resource Allocation and Planning ought to extend beyond the generation of a plan. Firstly, exercise data reveals that there are more support functions that a system can provide. Secondly, it is highly unlikely that any single human or machine will have sufficient knowledge on its own to generate viable plans; so planning, as now, will involve co-operation between a number of individuals. This joint exploration and elaboration of plans presents very different requirements to those pertaining during the development of AI planners to date (Tate 1986).

The project will consist of these highly related parts:

- a study consolidating information on user requirements and team structures for the chosen specific domain, e.g. from SP2.1.1.4 "Design Methods and Tools for Task Analysis";
- development of a prototype supporting simulation, plan representation and explanation;
- an investigation, with prototyping, into planning, counterplanning and replanning within the chosen domain.

A strong candidate domain is Anti-Submarine Warfare because a large amount of relevant information already exists from exercise observations.

4.3.1.4 Project Rationale

The two issues tackled by these projects are felt to be the most significant ones that are not addressed by other parts of the overall research programme. The projects are intended to counter two major assumptions in the main TDS programme - that the system will largely be based on one ship with all needed information delivered directly to it, and that knowledge based systems will be capable of doing all synthesis and analysis tasks with simple "approval" being given by operators. The same issues of distributed resources and the need for operator participation in planning are present in the TMD sphere.

4.3.2 Technology-Led Projects

4.3.2.1 Objectives

This category covers topics that are felt to be of relevance and importance but which are best tackled by specific **technology-led** projects. Because a number of these projects are already underway at ARE or elsewhere, expanded project descriptions are only provided for the new projects, that is SP3.1.2.4, Intelligent Training Facilities for C^2 Systems, SP3.1.2.5, Genetic Algorithms for C^2 Systems and SP3.1.2.6, Machine Learning of Temporal Patterns for Command and Control.

4.3.2.2 Research Issues

The projects within this section do not so much address issues as investigate the relevance of various technologies to Command and Control problems. Thus, projects taking leading-edge technical fields such as Neural Networks and Genetic Algorithms are focussed around well-understood problems such as those arising from the Data Fusion module in existing work. The issues are whether or not each technology is relevant and the contribution they could make to future system developments.

4.3.2.3 Research Projects

SP 3.1.2.1 The Application Of Neural Networks to Data Fusion

To study alternative inherently parallel knowledge representation models, specifically Neural Networks, in order to discover whether it is feasible to map the data fusion domain onto these models. This work to include:

- the completion of the Neural Network track classification system and its evaluation in relation to more conventional statistical track classification methods;
- extension of the Neural Network system to include wider issues such as the correlation of dissimilar data;
- completion of the mapping of the Neural Network development system and the neural networks it generates onto a parallel hardware platform, such as a transputer array or the Rekursiv object-oriented machine.

SP 3.1.2.2 The Application of Machine Learning to Data Fusion

To apply the process of Machine Learning initially to a Data Fusion Knowledge Base and thereby seek to improve its efficiency, refine its rule base and enhance its ability to acquire new kinds of knowledge. The project will include:

- identification of performance measures and instrumentation for data fusion system, and of suitable Machine Learning tool and application methodology;
- development of machine learning framework for learning data fusion rules and/or enhancements;
- generation of example scenarios;
- experiments to enhance the system's capability by acquiring new kinds of knowledge (e.g. patterns of enemy behaviour).

SP 3.1.2.3 Application of Formal Methods in the Development of KBS

To conclude the assessment of the applicability of techniques for converting formal representations of software into executable code and to assess the practicality of using them; to discover methods for generating appropriate strategies for testing a KBS from a formal representation of its knowledge base; to assess the level of coverage and rigour of mathematical proof required in developing a KBS; to develop a preferred approach to the application of existing formal development methods to the development of real-time blackboard KBS; to develop a notation and associated proof methods for the specification, development and validation of real-time blackboard KBS.

SP 3.1.2.4 Intelligent Training Facilities for C^2 Systems

The TDS will be a large, complex and functionally rich system for which there will be a number of different users. This project examines the development of embedded intelligent training facilities within the on-ship systems that will interactively exercise operators for initial and in-service familiarisation with the system's capabilities. The project will draw on work in Intelligent Computer Aided Instruction (ICAI) that embraces student modelling, tutoring strategies, scenario simulation and representation of domain and system knowledge.

SP 3.1.2.5 Genetic Algorithms for C^2 Systems

Genetic Algorithms (GA) are a class of optimised search system based (loosely) on an "evolutive" pseudo-random perturbation of patterns. They avoid problems such as hill-climbing in classical best-first search approaches and can be efficient in processing terms. Unlike Neural Networks, at the current time, they are particularly applicable to synthesis problems such as resource allocation and planning.

This project is aimed at small-scale experiments in applying GAs to aspects of Command and Control problems for an assessment of their relevance and future impact.

SP 3.1.2.6 Machine Learning of Temporal Patterns for Command and Control

Explores representation of temporal structure of events with grammars and automatic acquisition of grammars from scenario data. Stochastic Automata learning systems show strong convergence capability and would be an appropriate paradigm for recognition and generation of certain characteristics of command and control domains.

4.3.2.4 Project Rationale

The projects within this section can be characterised as having high potential pay-off, but also high risk. They are small, highly focussed experiments aimed at assessing technologies that have shown considerable promise in other related fields. Part of the remit for each should be to acquaint the SDIO and ARE with the status of current research relevant to their objectives.

4.4 Category 4: Central Support

4.4.1 Naval and TMD

4.4.1.1 Objectives

In formulating the research projects it was recognised that there were some activities associated with the research programme that did not conveniently fall into the other categories but were nonetheless important. The objectives of central support projects are to:

- support a range of both TMD and Naval projects ;
- prepare the way ahead for work beyond that directly included in the 3 year research programme.

4.4.1.2 Research Issues

These are either support projects or they start the process of combining the results of other projects.

4.4.1.3 Research Projects (Category 4) and Rationale

SP 4.1.1.1 Specification of Advanced Battle Management Prototype

The aim of this study is to lay the foundations of a future design and implementation project that would follow on at the end of the currently planned 3 year programme. The study will take place at the end of the programme and will combine and focus the results of the other projects. It will generate a requirements specification for an Advanced BMC^2 Demonstrator that combines all the functional levels of command and control previously explored. It will be the initial step towards a new generation demonstrator (or demonstrators) that will encompass the lessons of the previous demonstrators but will incorporate more advanced techniques and capability.

Tasks envisaged will include: analysing the results of the TDS and evaluation of the research programme; drawing up and assessing the feasible functionality of the demonstrator; establish outline architecture of demonstrator; draw up a requirements specification and establish a costed programme for implementation.

At this stage it is appropriate to leave open the question of whether there will be separate Naval and TMD Advanced BMC^2 Demonstrators.

SP 4.1.1.2 Scenario Generation and Data

All experiments will require resource for scenario generation and/or interface data. This project is intended to reserve some programme resource for that activity without, at this stage, being too specific as to how this will be achieved for individual projects. Clearly a high level of commonality will exist and use of other scenario generators is anticipated (eg. the SDIO sponsored work at RAE/SSL and at Hunting Engineering).

An early exercise will assess the detailed requirements of the proposed projects and determine their needs for scenario and other input data. In addition, work would include: writing software tools to convert and operate on data available as output from other sources; collecting and analysing relatively raw data and the producing new simulators and other software for scenario data generation.

The project is an essential and early part of the programme and the assessment exercise must be started immediately in order to influence other projects. The detailed scenario data requirements for many projects has yet to be determined and the source and availability of data is likely to be variable.

SP 4.1.1.3 Provision of HCI Investigation/Trials Facilities

HCI work such as task analysis and evaluation of the potential impact of KBS systems on the operational environment are likely to require the use of large high fidelity simulation facilities or interaction with in-service systems. Provision needs to be made for the allocation of such a resource to a number of projects. A short investigation is needed initially to determine in more detail the requirements for this project and the extent to which other work such as that being carried out by AXC5 at ARE is relevant, in particular for Naval applications and HCI projects. This work would also indicate the extent to which these projects rely on other Naval resources and initiate the acquisition of those facilities.

This project primarily supports other HCI related projects in the Naval domain.

SP 4.1.1.4 TDS Facilities Management

Many of the proposed projects plan to use the TDS. To provide use of these facilities will require a range of tasks that would include: software and hardware maintenance, configuration control, scheduling users, supporting use for scenario generation and supporting use for system training.

SP 4.1.1.5 Programme Management

The research programme will require significant staff resource for its management. This project is included to ensure an allocation for such support is included in the programme. Management and co-ordination of the complete research programme. will include tasks such as: planning; control and direction of individual research projects; issuing of RFPs/ITTs and bid evaluation;liaison with ARE and other MOD agencies; liaison with and reporting to SDIO/SDIPO; financial monitoring and control of projects and programme, strategy and organisation of the programme.

Discussions and advice from those involved in managing other research programmes such as Alvey and ESPRIT suggest that programme management effort needs to be from 7 to 14% of the total budget and is a significant element in achieving value from a research programme of this nature.

SP 4.1.1.6 Programme Evaluation

The programme will require staff resource to provide support with the evaluation of the results and achievements of projects and the programme. The work is closely related to project management. However, it is a separate and independent activity in the sense that it reviews and assesses the value and success of the whole programme, including the programme management. Programme evaluation will provide the support data and analysis to measure the programme and projects against their objectives. The work would focus and highlight the results and benefits of the programme and assist in determining the way forward. As such it will include coverage of ARE Experimental Programme Research Objective (EXPRO) 7 assessing the extent to which the TDS falls short of that needed for a future operational system.

SP 4.1.1.7 TDS Trials Data Processing

This project makes provision for the processing and reduction of data recorded during trials of the TDS. It was identified as requirement 5.2 in ARE research programme document ARE/23.01.02/90. It is an essential work item in the experimental use of the TDS and would commence at the end of TDS Phase 4, following an earlier identification and estimation of the detailed requirements.

5 TECHNICAL OBJECTIVES

This section presents an alternative perspective on the proposed research programme, that from the technology streams. It brings together the early SANDERLING work on technology prioritisation and examines how this is reflected in the choice of projects that have been presented in the previous sections.

The analysis phase of the SANDERLING project defined six technology streams: Hardware Architectures, Real-Time Systems Design, Knowledge Representation and Manipulation, Human Computer Interaction, Database/Knowledge Base Interaction and Development Methods. In the following sections a summary is first given of which sub-topics fall within each of these streams, and their relative prioritisation, before the discussion on which SANDERLING Projects the streams contribute to.

Table 5.1 provides an illustration of the contribution from each of the technology streams to the set of SANDERLING Research Projects. It makes reference to the project descriptions for the following text.

5.1 Hardware Architectures

5.1.1 Subtopics and their Ranking

Four related aspects of the development of high performance systems fall under the hardware architecture banner :

Paradigms: There are a range of paradigms available for implementing KBS solutions to a problem (e.g. production systems, blackboards). Each of these generic paradigms is usually tailored for a specific application. When considering new architectures for the solution to a problem (e.g. exploiting parallel processing) a paradigm should be analysed for its appropriateness to that architecture and either revised or replaced with one that is synergistic with the architecture.

Architectures: The study of new software and hardware architectures for solving complex problems is a continual area of research. Developments in language-specific processors, parallel shared-memory and distributed-memory computers, massively parallel machines, storage media and communication mechanisms all have a direct influence on attainable performance if they can be exploited for the application.

Tools: The use of tools to help produce, analyse and verify a particular solution to a problem is desirable, both in terms of generating a solution efficiently and in ensuring that the solution chosen maximises a set of performance criteria. Tools that can determine the mapping of a particular algorithm or paradigm to an optimal processing architecture, and for measuring the subsequent performance on that architecture are of particular interest.

Neural Networks and Genetic Algorithms: Novel processing mechanisms, of which these are two relevant examples, often display remarkable performance. It is important to build and maintain a balanced view of the contribution such new techniques may offer to problem domains.

Number	Title	Hardware Architectures	Systems Design	Knowledge Representation and Manipulation	Human Computer Interaction	Database Knowledge Base Interface	Development Methods
SP1.1.1	TDS Scalability	Medium	Medium				Low
SP1.1.2	Enhance TDS by KB Optimisation	High	Medium				
SP1.1.3	Training for TDS				High		
SP2.1.1.1	Database / KBS Interfacing					High	
SP2.1.1.2	Metrics for TDS Evaluation						High
SP2.1.1.3	Impact of TDS on Operating Environment				High		
SP2.1.1.4	Methods and Tools for Task Analysis				High		
SP2.1.1.5	HCI Design for Tactical Pictures				High		
SP2.1.1.6	Effects of Operator Interaction with TDS				High		
SP2.1.1.7	Assessment of TDS MMI				High		Low
SP2.1.1.8	Evaluation of TDS as a Data Fusion System				Medium		Medium

Table 5.1 (a) TDS and TDP Support Projects

Number	Title	Hardware Architectures	Systems Design	Knowledge Representation and Manipulation	Human Computer Interaction	Database Knowledge Base Interface	Development Methods
SP2.1.2.1	Enhanced SAP			High	Medium	Medium	
SP2.1.2.2	Enhanced RAP			High		Low	
SP2.1.2.3	Enhance TDS with Concurrency	High					
SP2.1.2.4	HCI for Situation Assessment and Resource Allocation				High		
SP2.1.3.1	Techniques for KBS Maintenance						High
SP2.1.3.2	Techniques for Knowledge Acquisition						High
SP2.1.3.3	Methods and Tools for A Posteriori Validation						High
SP2.1.3.4	Explanation in Situation Assessment				High		
SP2.1.4.1	Adaptive Interfaces for Command and Control				High		
SP2.1.4.2	KBS for Amphibious Operations			High	Medium		

Table 5.1 (b) Laboratory / TDS Enhancements, Use of Lab Demo and Stand-Alone Prototypes

Number	Title	Hardware Architectures	Systems Design	Knowledge Representation and Manipulation	Human Computer Interaction	Database Knowledge Base Interface	Development Methods
SP2.2.2.1	Specification of KBS						High
SP2.2.2.2	Verification and Validation of KBS						High
SP2.2.2.3	Robustness of KBS Architectures	Medium					High
SP2.2.2.4	Operational Adaptivity of Knowledge Bases						High
SP2.2.2.5	Integrating Knowledge Representations		Low	High		Medium	
SP2.2.2.6	'Non-Expert' KBS			Low			Medium
SP2.2.2.7	Real-Time Integrated Databases					High	
SP2.2.3.1	Adaptive Preferential Defence	Medium	Low	Medium	High		
SP2.2.3.2	Sensor Management		Low	High	High	Low	
SP2.2.3.3	Intention Prediction of Manoeuvering Objects			High	Medium	Low	
SP2.2.3.4	Development Methods Prototype			Low			High
SP2.2.3.5	Hybrid Approach to Data Fusion	High					

Table 5.1 (c) Use of TMD Prototypes and Stand-Alone TMD Prototypes

Number	Title	Hardware Architectures	Systems Design	Knowledge Representation and Manipulation	Human Computer Interaction	Database Knowledge Base Interface	Development Methods
SP3.1.1.1	Distributed Situation Assessment	Low	High	Low	Medium		
SP3.1.1.2	Co-operative Planning Aids			High	High		
SP3.1.2.1	Neural Networks	High					
SP3.1.2.2	Machine Learning						High
SP3.1.2.3	Formal Methods in KBS Development						High
SP3.1.2.4	Intelligent Training Facilities				High		
SP3.1.2.5	Genetic Algorithms	High					
SP3.1.2.6	Stochastic Learning Automata	High					

Table 5.1 (d) Enabling Research

The evaluation of these subtopics, discussed at length in Part B of the SANDERLING Final Report, led to the following ranking order:

1. Paradigms
2. Tools
3. Hardware
4. Neural Networks and Genetic Algorithms.

One of the principal reasons for this is the expectation that many existing research programmes worldwide will progress the state of the art in tools and hardware areas without them needing support from the SANDERLING Programme. Work on paradigms, however, is more application dependent and therefore needs to be addressed in project descriptions. While Neural Networks and Genetic algorithms rate low according to the criteria used for this ranking exercise, this does not imply that they should be discarded as potential research topics, for the simple reason mentioned above.

5.1.2 Project Perspective

The sub-topic ranking is directly reflected in the SANDERLING Projects, where the emphasis is heavily on development and experimentation with efficient methods for implementing either the current rule-based model or alternatives. This reflects the view that efficient implementation mechanisms will have a greater long-term importance than current hardware. Investigation of tools for supporting development of such methods, for example on parallel systems, is confined to those projects that are actually developing demonstrators (e.g. SP2.1.2.3) rather than those studying existing demonstrator capabilities (e.g. SP1.1.1 and SP1.1.2). Similarly, hardware itself is relegated to a position of being considered only when necessary, e.g. when a parallel processing environment is needed for eventual implementation and evaluation of a concurrent implementation, as in the final task of SP2.1.2.3 "Enhance TDS Performance by Concurrent Processing".

The proposed research into paradigms is split between that concentrating on efficient implementation of the existing mechanisms (of TDS and for TMD) and that investigating extensions for situation assessment or resource allocation (SP2.2.3.1) and integration of knowledge based and algorithmic methods (SP2.2.3.5). The latter project provides by far the most appropriate vehicle for the explicit study of paradigm issues because of the availability of detailed data and information on the existing methods. The project therefore includes the largest amount of effort devoted to issues of the Hardware Architectures stream.

The sub-topic of Neural Networks and Genetic Algorithms, or what might better be categorised as "radically different" approaches to Command and Control problems, has led to two project proposals in the "Enabling, Technology Led" category. The Neural Network project is intended partly as support for continuing sponsorship of work at Aberdeen University on applying the technology to Data Fusion problems.

Projects SP1.1.1 and SP1.1.2, 'Investigate the Scalability Problems Inherent in the TDS' and 'TDS Knowledge Base Optimisation', respectively, have a high contribution from the Hardware Architectures stream and are potentially very influential. If the results from these projects show difficulties in obtaining the required performance from the rule-based approach to knowledge representation, this will have a serious effect on the viability of other demonstrators.

5.2 Real-Time Systems Design

5.2.1 Subtopics and their Ranking

This stream consists of only two subtopics:

Real-Time AI Systems Design: This is concerned with several specific problems in the development of reasoning systems which have the capability to operate in real-time. For example, these must deal with interrupts, be able to prioritise processing and guarantee response times.

Distributed Artificial Intelligence: DAI is concerned with the design of co-operating knowledge based systems. It addresses such issues as communications, partitioning of problems across processors, control of the reasoning process(es) and maintaining consistency of reasoning.

There is little to choose between the two sub-topics and their contribution to projects is to a large extent determined by the ability to use the main demonstrators (TDS, SAP, RAP, etc.) as vehicles for work in these areas. It would be difficult to use the existing Data Fusion or proposed situation assessment prototypes to explore DAI issues without unacceptable expenditure reworking code.

5.2.2 Project Perspective

Real-Time AI considerations in the SANDERLING Projects are secondary to performance issues. In terms of the potential payoff from these streams, the relationship is a sensible one.

In general, the projects to which the Real-Time AI sub-topic makes a contribution are the same as those to which Hardware Architecture Paradigms contribute strongly. For example in SP1.1.2 "TDS Knowledge Base Optimisation", the exploitation of techniques for progressive reasoning or prioritisation within the existing rule-bases may give the performance enhancements sought without recourse to re-implementation in an alternative paradigm. The exception is SP2.2.2.5 "Integrating Knowledge Representations" which is concerned more with the development of a common language for representation that is intrinsically efficient.

Distributed AI has been deliberately excluded from the mainstream of Naval and TMD application led projects, not because it is unimportant but because the issues are best addressed in isolation from the TDS and TMD prototypes. A specific project has been created for consideration of Distributed AI issues (SP3.1.1.1 "Distributed Situation Assessment") in order that the practical aspects of using knowledge based decision support systems on several ships within a task force, or at several sites within a TMD architecture, can be addressed. The intention should be to exploit as much as possible of work being done elsewhere, specifically the development of tools to address the issues central to the Naval and TMD domains.

5.3 Knowledge Representation and Manipulation

5.3.1 Subtopics and their Ranking

The Knowledge Representation and Manipulation stream contains, as its name suggest, two distinct categories of sub-topic, those relating to the development of representations for specific characteristics of the command and control domains, and those dealing with the development of mechanisms for the manipulation or use of such structures. Without a consistent representation for this type of information, *ad hoc* schemes will proliferate for functions that require interpretation of actions or their planning. The sub-topics themselves are as follows, the first four falling within the former category and the other two the latter:

Temporal Representations: These deal with data and knowledge relating to events or activities that have explicit temporal content. For example, "Sweep area alpha *during* transit to staging point". Such data is essential to descriptions of patterns of events, i.e. plans for orange and blue force behaviour.

Spatial Representations: Spatial relationships are a key to description and understanding of scenes, and of command and control concepts such as "defensive screens" or "balanced distribution of forces".

Uncertainty: The representation of uncertainty in knowledge and data, and related topics such as incompleteness and the risk of error, have been central to knowledge based systems design in many domains. Command and Control domains are rife with problems related to uncertainty introduced by poor and incomplete sensing, and the risk associated with wrong decisions.

Modal Representations: This category of representations covers such things as the intentions of orange forces, their beliefs, knowledge, preferences and goals. Such things will also be applicable to descriptions of other blue forces, and to components of self-description.

Planning: Addresses the development of systems for reasoning about action in relation to sets of goals. This would include, in the command and control context, resource allocation, readiness maintenance and mission planning. This in turn necessitates representation of goals and possible actions for inclusion within a plan. Planning is particularly concerned with temporal ordering of activities and can adapt to uncertainty through the consideration of contingencies and plan robustness.

Reason Maintenance Systems: These are the part of reasoning systems which deal with non-monotonicity. They give a system the ability to deal with circumstances where new data affects previous conclusions, and allow multiple hypotheses (interpretations or predictions) to be maintained.

The ranking procedure resulted in the following ordering of subtopics (see Part B of the Final Report for further detail):

1. Temporal Representations
2. Uncertainty
3. Planning
4. Spatial Representations

5. Reason Maintenance Systems
6. Modal Representations

It is also important to bear in mind that, in relation to the overall goals of the SANDERLING Research Programme, the emphasis within the Knowledge Representation and Manipulation stream was proposed to be on enhancing the functionality of the Knowledge Based approach to command and control problems, for both Naval and TMD; the rationale being that a commitment had already been made to these aspects of representation and reasoning within the TDS and it would therefore be inappropriate to change them until or unless the functional performance of the TDS was shown to be inadequate.

5.3.2 Project Perspective

As anticipated, there is a clear emphasis of the Knowledge Representation and Manipulation effort on enhanced functionality. In the Naval case, projects such as the enhanced situation assessment and resource allocation prototypes receive the greatest input from this stream, along with the aspects of command and control within the amphibious operations programme (SP2.1.4.2). The TMD projects concerned with SA or RA functions similarly call for high input.

Because of the application focus of the majority of projects, the ranking of topics is not strongly reflected in them. There is generally a need to address all the representation issues together for complete coverage of a specific application problem.

For each topic there tends to be a key project:

- Planning, and particularly planning within the context of existing Naval operational structures, is a specific focus of SP3.1.1.2 Co-Operative Planning Aids for C^2. Reason Maintenance Systems feature heavily here too, because such hypothetical and non-monotonic reasoning has been shown to be prevalent in Naval planning behaviour. RMS features in a similar fashion in project SP2.2.2.5 "Intention Prediction of Intelligently Manoeuvering Objects", where multiple hypotheses of future states are required;

- Spatial, Temporal and Modal reasoning are almost always grouped together and are seen repeatedly in projects attempting to deal with the higher level C^2 functions. The choice of an appropriate set of primitive descriptors for these types of knowledge and data is a fundamental and crucial requirement. Without them there will be a good deal of repeated work and wasted effort. For these sub-topics, SP2.1.2.1 "Enhanced situation assessment Prototype" is a test-ground, providing input for projects such as SP2.1.2.2, "Enhanced resource allocation Prototype", and SP2.2.3.3, "Integrating Knowledge Representations".

- Uncertainty is perhaps an exception to this rule as it will form a central part of all projects performing prototyping around the TMD application. For example, the inherent uncertainty of data is a critical issue in SP2.2.3.5 "Hybrid Approach to Data Fusion" and coping with uncertainty a factor in SP2.2.2.5 "Intention Prediction of Intelligently Manoeuvering Objects".

5.4 Human Computer Interaction

5.4.1 Subtopics and their Ranking

Human Computer Interaction is subdivided into the following sub-topics:

Physical Interface: This embraces the controls, displays and 'dialogue' which an operator uses to interact with the computer. Research concerns the physical and perceptual aspects of the design of these system elements.

Design Methods and Tools: This refers to the various analyses, such as task analysis, goal analysis, knowledge elicitation, allocation-of-functions for specifying the users' requirements, and to the various techniques employed to carry out these analyses. The methods and tools span the entire system development process and therefore include prototyping and evaluation activities.

Modelling Issues: This covers how users form models of their world (domain models), models of the system and problems of system "transparency", and how to construct models of the user within the system (i.e. embedded user models or adaptive interfaces).

Cognitive Issues: This is concerned with various aspects of the user's cognitive abilities and limitations such as, for example, reasoning with uncertainty, hypothesis fixation, confidence. It concerns explanations (i.e. computer explanations to the user) and includes the familiar problem of mental workload.

User Support: Referring to issues such as training (both on-line and off-line), help facilities, and the provision to the user of decision aids such as predictive displays.

Organisational Issues: This relates to teamwork, team structure and job design. It is particularly relevant to the determination of the role of knowledge-based decision support systems if they are operate in a co-operative manner with people.

These duly received a ranking as follows:

1. User Support.
2. Physical Interface.
3. Design Methods and Tools.
4. Modelling Issues.
5. Cognitive Issues.
6. Organisational Issues.

Though there was a considerable gap between the first three of these and the latter, all the topics are felt important to the operational success of knowledge based decision support systems.

5.4.2 Project Perspective

In the research programme presented above, HCI plays a very prominent role, appearing in nearly half the proposed projects. Each of the subtopics described above is well represented.

The prominent position of HCI within the proposed projects reflects the overall importance that needs to be attached to it in making the developed systems deployable. To some degree the amount of effort put in to HCI research will be adjustable, because of the presence within the programme of several demonstrators of which HCI forms a part, e.g. Enhanced SAP and RAP (SP2.1.2.1 and SP2.1.2.2), SA and RA functions for TMD (SP2.2.3.1, SP2.2.3.2, SP 2.2.3.3) and stand-alone prototypes (SP2.1.4.2 and SP3.1.1.1). As is common in such demonstrator development, the question arises as to whether to develop a user interface appropriate to the potential final end user, or to place the emphasis on developing HCI which will contribute to the developers' understanding of the behaviour of the system and its aptness as a demonstrator.

Human Computer Interaction issues are the direct motivation for many projects in the proposed programme. *User Support*, for example, is the aim of projects SP1.1.3 "Training for TDS" and SP3.1.2.4 "Intelligent Training Facilities". The *Physical Interface* is addressed in SP2.1.1.5 "Optimisation of HCI Design for Tactical Picture Displays". *Organisational Issues* are a focus for projects such as "Co-operative Planning AIds" (SP3.1.1.2) and "Distributed Situation Assessment" (SP3.1.1.1). *Design Methods and Tools* for Task Analysis are the subject of investigation in SP2.1.1.4. "Adaptive Interfaces for Command and Control" (SP2.1.4.1) is a basis for addressing *Modelling Issues*. Finally, *Cognitive Issues*, and specifically explanation, are the subject for SP2.1.3.4 "Exploration of Appropriate Techniques for Explanation in Situation Assessment Systems".

However, the potential contractual inefficiency of this proliferation of projects addressing HCI issues led to the introduction of SP2.1.2.4 "HCI for situation assessment and resource allocation". This project applies some well-established methods and tools to a specific target HCI design which will address physical interface, modelling and cognitive issues.

Projects aimed at evaluation of the TDS (such as SP2.1.1.3, SP2.1.1.6, SP2.1.1.7 and SP2.1.1.8) assume that there are models for user requirements covering most of the HCI issues above. By implication, these projects will therefore need to review existing material and the state of the art in order to adopt a position for evaluation.

5.5 Database / Knowledge Base Interaction

5.5.1 Subtopics and their Ranking

The six sub-topics within this stream are described below. The research issue in each case is the applicability of the method in command and control systems and the design of appropriate systems, given performance and storage requirements

<u>Coupling</u>: One of the options in considering database and knowledge base integration stresses the different, but complementary nature of the technologies, and treats each as a discrete component.

<u>AI-enhanced Databases</u>: Existing database storage and access mechanisms are being enhanced by the introduction of new storage models (e.g. changing the simple relational model for, say, a semantic network) or access methods (e.g. embedding knowledge of database contents into the access mechanism to allow richer query languages to be supported).

Intelligent Front-Ends / Natural Language: Richer still query support is the aim of research in these areas. The interaction as a whole (rather than on a query by query basis) affects the behaviour of the retrieval mechanisms, allowing anaphoric reference in query expressions. Additionally, knowledge of the database can be used to optimise search paths by translating from the access request to the database query language statement. The research stream has implications for direct human access to the databases as well as the interaction between the database and a knowledge base.

Novel Database Structures: The most prevalent and relevant example here is object-oriented databases that extend such data structuring mechanisms from dynamic programming environments to storage. This represents a considerable step because of the capability in Object-Oriented languages of embedding procedures which are activated when their related data items are accessed.

Dynamic Databases: The ability to maintain and make accessible real-time data from a profusion of sources makes demands on databases that are not catered for by commercial DBMS. Mechanisms such as caching or reductionism (limiting relation and query structures) may enhance database speeds, but would need to be developed in an application-specific manner.

Knowledge Base Management Systems (KBMS): This is the term for the situation where database and knowledge based system are part of the same overall mechanism, i.e. data and knowledge are stored in a homogeneous form and accessed in the same manner. The area is as yet immature but has potential benefits in terms of performance and programming capability.

The ranking procedure produced the following ordering:

1= Coupling and Dynamic Databases.
3. AI Enhanced Databases.
4. Knowledge Base Management Systems.
5. Intelligent Front Ends.
6. Novel Database Structures.

The joint first topics were ranked considerably higher than the others.

5.5.2 Project Perspective

The desired emphasis on Coupling between conventional databases and knowledge based systems, Dynamic Databases and Knowledge Base Management Systems is supported by the inclusion in the programme of projects SP2.1.1.1 "Investigate Database/Knowledge base interfacing Techniques for Application to the TDS" (the former two) and SP2.2.2.5 "Integrating Knowledge Representations" (KBMS). SP2.2.2.7 "Real-Time Integrated Databases" addresses the design of dynamic object-oriented databases that are a likely requirement for TMD systems. Other subtopics within the stream receive varying degrees of attention in the demonstrator development projects.

A number of the projects to which the Database/Knowledge Base stream makes a contribution involve the efficient storage of the new representations developed for those projects. This is particularly the case in projects concerned with demonstrator development for enhanced functionality in both Naval and TMD programmes (e.g. SP2.1.2.1 "Enhancement of the Situation Assessment Prototype). This inclusion within many demonstrator projects of a Database/Knowledge Base component accounts for the emphasis on enhanced databases of various kinds to be found in the technical project descriptions of Annex C2. In a similar way to the HCI stream, the amount of effort expended in researching database issues can be varied within quite broad limits, since the database issues are not central to obtaining enhanced functionality.

5.6 Development Methods

5.6.1 Subtopics and their Ranking

This stream contains a number of related sub-topics as follows:

KBS Specification: This sub-topic addresses all aspects of specification development as they apply to KBS. KBS differ from other software in having a different development cycle, which generally involves successive prototyping. The ability to write a specification at any point is therefore of interest, as are the particular contents of such a specification.

KBS Validation and Verification: There is a clear interaction between this sub-topic and KBS Specification, since something that has no specification can not be validated. The issue within this sub-topic is the development of techniques that can be applied to KBS in terms of the types of programming involved and their method of construction.

KBS Life Cycle Model: This is concerned with investigating life-cycle methodologies, in other words the methods for controlling the development of KBS, that have been developed, for example KADS.

Knowledge Acquisition: Addresses methods for eliciting specific types of construct found in command and control domains, such as spatial and temporal relations. The applicability of existing methods and tools to such knowledge is also considered in this sub-topic.

KBS Development Tools: Tools are available to assist in the development, testing and maintenance of KBS. For example, systems that perform some rulebase consistency checks exist, as do ones that integrate knowledge acquisition and development processes. The applicability of existing tools and the viability of building domain specific ones is the objective for this sub-topic.

Robust Architectures for KBS: Within conventional software engineering there are a number of techniques for ensuring the robustness of software through control of the design and validation processes. The applicability of these to KBS design is to be addressed.

KBS Maintenance: Because of the types of function KBS are expected to perform in the command and control context, it is highly probable that there will be numerous changes required in the knowledge bases. These changes may occur over both short and long periods, for example changes to tactics are short-term, whereas changes to ship libraries will happen over longer timescales. This sub-topic addresses how knowledge bases can be designed for updating and how the process should be managed.

Machine Learning: ML has a potential impact in two areas: as an adjunct to other knowledge acquisition methods at the development stage, and as a mechanism for improving or expanding system performance, i.e. as part of a maintenance and updating process.

The ranking process produced the following ordering of sub-topics:

1. KBS Validation and Verification.
2. KBS Specification
3. KBS Maintenance
4. Knowledge Acquisition
5. Robust Architectures for KBS
6. KBS Development Tools
7. Machine Learning
8. KBS Life Cycle Model

This ranking is heavily influenced by the practicalities associated with deploying TDS and takes account of the substantial amount of work in progress elsewhere on aspects such as Life-Cycle Models.

5.6.2 Project Perspective

Reflecting the importance attached to this stream during the technology evaluation phase, there are several specific projects in the programme designed to address individual subtopics.

The Naval programme, on the back of the TDS, forms the basis for experimenting with evaluation, validation and maintenance issues. For example, SP2.1.1.2 "Derive KBS Performance and Competence Metrics for the TDS Evaluation Programme", SP2.1.3.1 "Development of Techniques for KBS Maintenance" and SP2.1.3.3 "Development of Methods and Tools for the Validation of KBS" are all projects focussed on the TDS involving input from this stream.

From the TMD side, project SP2.2.3.4 "The Development Methods Prototype" exists as a vehicle for several projects related to this stream's sub-topics: Specification (SP2.2.2.1), Verification and Validation (SP2.2.2.2), Robustness (SP2.2.2.3) and Operational Adaptivity (SP2.2.2.4).

TMD also provides a vehicle for examining issues relating to specification in KBS procurement, specifically the Battle Management Prototype in SP4.1.1.1, and validation of systems where there are no experts involved in the knowledge acquisition process, SP2.2.2.6.

The programme therefore provides a solid grounding for the subtopics felt to be of most relevance to deployment of knowledge-based C^2 systems: validation, verification, maintenance and specification.

The programme also caters for examination of the more esoteric issues within this stream, such as machine learning and formal specification techniques. These appear under the enabling research programme.

6 EVALUATION

6.1 Objective

The proposed research projects in section 4 are estimated to cost approximately twice that of the planned budget of £7m. The aim of this evaluation section is to assist in the selection of projects and the definition of a recommended programme that is close to the planned budget.

6.2 Evaluation Criteria

6.2.1 Primary Criteria

The two primary criteria for evaluating projects are as follows :

Criticality : how critical is this project to the achievement of the objectives of the Research Programme, as defined in Part A ? The criticality of each project is assessed as high, medium or low in relation to each objective;

Risk / timescales : how high are the technical risks incurred in attempting to achieve significant progress ? In most cases the risk will be associated with long research timescales. Risk is estimated on a score of high, medium or low.

6.2.2 Secondary criteria

Secondary criteria to be used are:

Link projects : these are the projects on which other projects have strong dependencies, either providing an experimental platform or generating results which are required by the other projects. These dependencies are not listed in the evaluation tables, but are identified and discussed in the final Type A lists;

Defined deliverables: the deliverables generated by the project - priority is given to projects which have clearly defined short term deliverables, eg. tools, prototypes;

Special Research: the degree to which the research is unique to Naval/TMD C^2 - priority is where the research is very specific to Naval/TMD C^2 and is very unlikely to be carried out elsewhere;

Special Capability : the extent of UK expertise in the area, expressed as :

- High : UK group(s) with world lead
- Medium : Good general UK capability
- Low : Low UK capability

Priority is where the UK is known to have a special edge in a research field;

Result / cost : The ratio of expected results to estimated cost, expressed as :

- High : significant results can be expected for relatively low investment, typically where a project builds on existing work and/or uses available resources

- Medium : a reasonable return on investment, typically where a project builds on a high general level of understanding and does not require special resources

- Low : significant progress can only be achieved through high research investment. The project may break completely new ground and/or require specialised resources

Priority is for projects that maximise the result / cost ratio - eg. by building on existing work or utilising available hardware resource.

6.3 Procedure

The evaluation process involved the following steps :

1. Grouping of the projects into categories that are related to the top-level programme objectives and the experimental platforms to which they are targetted (see section 3 for details on categories).

2. Assessing and adjusting the balance between categories and technologies (see section 2 for a discussion of that balance). Each category has been allocated a budget according to the table in section 6.4.

3. Assessing each project against the set of criteria defined above. Within each category, a decision table has been constructed, describing each project against the criteria.

4. Identifying the '**link**' projects within each category, and the projects which depend on them.

5. Evaluating the projects within each category, according to the criteria described above.

6. Defining an options list of projects with a recommended short list that meets the planned £7m budget. Projects have then been selected to form an options list consisting of two types of projects, A and B, depending on the extent to which each contributes to objectives of the programme, namely:

   - Type A fall within the target budget for that category defined in 6.4.

   - Type B fall outside the planned budget allocation, but within twice the allocation.

6.4 Budget Allocations

On the basis of sections 2 and 3 which discussed the balance between categories, the target Type A project budgetary allocation is:

Category		Budget (£'000)	%
1	TDS Deployment	350	5
2.1	Applied Research - Naval	2100	30
2.2	Applied Research - TMD	2450	35
3	Enabling Research	1400	20
4	Central Support	700	10
TOTAL		7000	100

6.5 Evaluation Matrix

The following matrix summarises the results of the evaluation of the research projects. Each of the criteria is assessed in the terms described in section 6.2. The evaluation procedure has not been applied to the Category 4 projects. Since these provide central support facilities for many of the projects, they are assumed to be essential to the programme and are included in total in the costs.

Project	OpDep	EnFun	TMD	Risk / Timescales	Defined Deliverables	Special Research	Special Capability	Results / Cost
1.1.1 Scalability of TDS	High	Medium	Medium	Medium	Evaluation Report, metrics & Tools	Special	Medium	Medium
1.1.2 Enhance TDS Performance by KB Optimisation	High	Medium	Medium	Low	Analysis & Report, enhanced prototype	Special	Medium	High
1.1.3 Development of training for the TDS	High	Low	Low	Low	Course material, Report & Tools	Special	Medium	High

Project	OpDep	EnFun	TMD	Risk / Timescales	Defined Deliverables	Special Research	Special Capability	Results / Cost
2.1.1.1 Investigate Dbase / Kbase Interfacing	Medium	Medium •	Low	Low	Report	General	Medium	High
2.1.1.2 KBS Metrics	High	Medium	High	Medium	Report, metrics	General	Medium	Medium
2.1.1.3 Impact on Operating Environment	High	High	Medium	Low	Evaluation Report	Special	High	Medium
2.1.1.4 Methods & Tools for Task analysis	Med/ Low	Med/ Low	Med/ Low	Low	Methods & Tools	General	Medium	High
2.1.1.5 Optimise HCI Design	Med/ Low	Med/ Low	Med/ Low	Low	Report, software tools	Special	Medium	High
2.1.1.6 Operator Interaction with C&C systems	Medium	Medium	Medium	Low	Report	Special	Medium	High
2.1.1.7 Assessment of MMI	High	Medium	Medium	Medium - High	Report	Special	Medium - Low	Low
2.1.1.8 Evaluation of the TDS as a Data Fusion System	High	Medium	Medium	Low	Evaluation Report	Special	Medium	High
2.1.2.1 Enhance Situation Assessment Prototype	Low	High	Medium	Medium	Enhanced prototype	Special	Medium - High	High
2.1.2.2 Enhance Resource Allocation Prototype	Low	High	Medium	Medium	Enhanced prototype	Special	Medium - High	High
2.1.2.3 Enhance TDS by concurrent processing	Low	Medium	Medium	Medium - High	Development environment, Report & demonstration prototype	Special	Medium	Medium

2.1.2.4 HCI for Situation Assessment	Low	High	High	Low	Prototype	Special	Medium	High
2.1.3.1 Techniques for KBS maintenance	High	High	High	Medium	Methods & Tools	General	Medium	Medium
2.1.3.2 Techniques for Knowledge Acquisition	Low	Medium	Medium	Low	Methods & Tools	General	High	High
2.1.3.3 Methods & Tools for Validation of KBS	Medium	Medium	Medium	Medium	Methods & Tools	General	Medium - High	Medium
2.1.3.4 Techniques for explanation in Situation Assessment	Low	Medium	Medium	Low	Report	Special	Medium	High
2.1.4.1 KBS enhanced HCI	Low	Medium	Medium	Medium	Report	General	Medium	Low
2.1.4.2 KBS Planners for resource allocation	Low	Medium	Low	Medium	Prototypes	Special	Medium	Medium - Low
2.2.1.1 Evaluate & Assess TMDD	N/A	N/A	N/A	Low	Evaluation Report	Special	High	High
2.2.1.2 Integrated Data fusion	N/A	N/A	N/A	Medium	Report & exploratory prototype	Special	Medium - High	Medium
2.2.1.3 Incorporation of Sit Assess & Res Alloc in TMDD	N/A	N/A	N/A	High	Report & exploratory prototype	Special	Medium	Medium
2.2.1.4 Integration of discrimination into TMDD	N/A	N/A	N/A	High	Report, prototype	Special	Medium - High	Medium
2.2.2.1 Specification of KBS	High	High	High	Medium	Methods & Tools	General	Medium	Medium
2.2.2.2 V&V of safety critical KBS	High	High	High	Medium - High	Methods & Tools	General	Medium	Medium - Low
2.2.2.3 Robustness of KBS	Medium	Medium	Medium	Medium	Report	General	Low	Medium - Low
2.2.2.4 Adaptivity of KBases	Medium	Medium	Medium	High	Report	General	Low	Low
2.2.2.5 Integrating knowledge representations	Low	Med/ Low	Med/ Low	High	Report & exploratory prototype	General	Medium	High

2.2.2.6 Validation of KBS based on non-expert knowledge	Medium	Medium	High	High	Methods & Tools	General	Low	Low
2.2.2.7 Real-time integrated databases	Medium	High	High	Medium	Prototype, Model	Specific	Medium	Medium
2.2.3.1 Adaptive preferential defence	Low	High	High	High	Report	Special	Low	Low
2.2.3.2 Sensor management	Low	High	High	Medium	Report	Special	Medium - Low	Medium - Low
2.2.3.3 Intention predictor	Low	High	Medium	Medium	Report, Prototype	Special	Medium - Low	Medium - Low
2.2.3.4 Development Methods Prototype	Low	High	High	Low	Prototype	Special	Medium - High	High
2.2.3.5 Hybrid Data Fusion	Low	High	High	Low	Prototype, Analysis Report	Specific	Medium - High	High

Project	OpDep	EnFun	TMD	Risk / Timescales	Defined Deliverables	Special Research	Special Capability	Results / Cost
3.1.1.1 Distributed SA	Low	High	High	High	Report	Special	Medium	Medium - Low
3.1.1.2 Co-operative planning aids for C&C	Low	High	High	Medium - High	Report & Prototype	Special	Medium	Medium - Low
3.1.2.1 Neural networks for data fusion	Low	Medium	Medium	High	Report	Special	Low	Low
3.1.2.2 Machine learning for data fusion	Low	Medium	Medium	High	Report	Special	Medium	Medium - Low
3.1.2.3 Formal methods for KBS development	Low	Medium	Medium	High	Report	General	Medium - High	Medium - High
3.1.2.4 Intelligent training systems	Low	Med/ Low	Med/ Low	Medium	Report	General	Medium - High	Medium - High
3.1.2.5 Genetic algorithms	Low	Med/ Low	Med/ Low	High	Report	General	Medium	Medium
3.1.2.6 Stochastic Learning Schemata	Low	Med/ Low	Med/ Low	High	Report	General	Medium	Low

6.6 Options List

The evaluation of research projects described in section 6.3 generated the results shown below. The projects listed as Type A comprise the set of recommended projects costing up to the budget limit for each category. The Type B projects make up the remainder, costing up to a total of twice the budgetary limit. The complete list of Type A and B projects is summarised in table 1, and is described for each category in the following sections.

Table 1 : Summary Evaluation of Projects

Type A: Projects within the target budget

		£'000
Category 1 :		
1.1.1	Investigate operational scalability of TDS	160
1.1.2	Enhance TDS performance by KB Optimisation	200
	Total :	360
Category 2.1:		
2.1.1.2	KBS Performance and competence	160
2.1.1.3	Evaluation of the operational impact of the TDS	120
2.1.1.7	Assessment of the TDS HCI	240
2.1.1.8	Evaluation of the TDS as data fusion system	160
2.1.2.1	Enhanced situation assessment prototype	560
2.1.2.4	HCI for situation assessment and resource allocation	480
2.1.3.1	Techniques for KBS maintenance	320
	Total :	2040
Category 2.2 :		
2.2.2.1	Specification of KBS for C^2	200
2.2.2.2	Verification and validation of safety critical KBS	480
2.2.2.7	Real-time integrated databases	240
2.2.3.2	Sensor management	680
2.2.3.4	Development methods prototype	320
2.2.3.5	Hybrid approach to data fusion	400
	Total :	2320
Category 3 :		
3.1.1.1	Distributed situation assessment	400
3.1.1.2	Co-operative planning aids for C^2	440

Category 3 (cont.)

3.1.2.1	Application of Neural Networks to data fusion	180
3.1.2.2	Application of Machine learning to data fusion	180
3.1.2.3	Formal methods for the development of KBS	280
	Total :	1480
Category 4 :		760
	Total Type A :	**6960**

Type B: Additional Projects within twice the target budget

Category 1 :

1.1.3	Training for TDS	320
	Total :	320

Category 2.1 :

2.1.1.1	Database / knowledge base integration	160
2.1.1.4	Methods and Tools for task analysis	160
2.1.1.5	Optimise HCI design of Tactical Picture Displays	200
2.1.1.6	Operator interaction	160
2.1.2.2	Enhance resource allocation prototype	400
2.1.2.3	Enhance TDS by concurrent processing	320
2.1.3.2	Techniques for knowledge acquisition	240
2.1.3.3	*A posteriori* validation of KBS	280
2.1.3.4	Techniques for explanation in situation assessment	160
2.1.4.1	Adaptive interfaces for C^2	120
2.1.4.2	KBS for Amphibious Operations support	360
	Total :	2560

Category 2.2 :

2.2.1.1	Evaluate and assess TMDD	240
2.2.1.2	Integrated data fusion using the TMDD	960
2.2.1.3	Incorporate SA and RA in TMDD	800
2.2.1.4	Integrate discrimination in TMDD	200
2.2.2.3	Robust architectures for KBS	160
2.2.2.4	Operational adaptivity of KBS	320
2.2.2.5	Integrating knowledge representations	180
2.2.2.6	Validation of 'non-expert' systems	80
2.2.3.1	Adaptive preferential defence	680
2.2.3.3	Intention prediction of intelligently moving objects	560
	Total :	4180

Category 3 :

3.1.2.4	Intelligent training systems for C^2	320
3.1.2.5	Genetic algorithms for C^2	180
3.1.2.6	Machine Learning of temporal patterns for C^2	180
	Total :	680
	Total Type B :	**7740**

6.6.1 Type A Projects

Category 1 : TDS Trials Support

Budget : £350K

Projects

SP 1.1.1 Operational scalability of the TDS
SP 1.1.2 Enhance TDS by KB Optimisation

All three projects category 1 projects are important to the TDS trials programme. Whereas the technical issues addressed in 1.1.1 and 1.1.2 are also extremely relevant to the TMD programme, 1.1.3 is largely a general support activity with a lower technical content, and must therefore be seen as less relevant in the context of the research programme. In view of the budget limitations, therefore, it is excluded from the Type A list.

Category 2.1 : Applied Research, Naval

Budget : £2100K

Projects

SP 2.1.1.2 KBS performance and competence **(link project)**

The generation of appropriate performance and competence metrics is central to many of the evaluation activities and is essential to the TDS trials programme. As such it directly addresses the ARE programme objective EXPRO 2, and will be of great importance to the TMD programme.

SP 2.1.1.3 Impact of the TDS on the operating environment

An assessment of the impact of the TDS on the operating environment is essential to the trials programme and directly addresses the ARE objectives EXPRO 5 & 6. The results of this project could have a significant impact on the long term prognosis for KBS technology in C^2 systems. The project is low risk, and since it relates specifically to Naval C^2 it is unlikely to be carried out in any other context.

SP 2.1.1.7 Validation of the TDS HCI

This project is essential to the TDS trials programme and directly addresses ARE objective EXPRO 4. The issues are special to Naval C^2 and are not covered by other projects such as SP 2.1.2.4.

SP 2.1.1.8 Evaluation of the TDS as a data fusion system

This project is also essential to the TDS trials programme and directly addresses ARE objective EXPRO 1. The issues are special to Naval C^2 and are not covered by other projects such as SP 2.1.2.4.

SP 2.1.2.1 Enhanced situation assessment Prototype

Both the Enhanced SAP (SP2.1.2.1) and Enhanced RAP (SP2.1.2.2) are important to the objective of increasing the functionality of the TDS. Both address issues that are unique to Naval C^2 and draw on existing UK capability. However, the SAP is currently at a more advanced stage of development than the RAP, and could be used to explore and develop new knowledge representation schemas, which may subsequently be used in the enhancement of the RAP.

SP 2.1.2.4 HCI for situation assessment and resource allocation **(link project)**

This project draws together many of the HCI issues (2.1.1.4, 2.1.1.5 and 2.1.1.6), and explores them in the context of situation assessment. The project will address HCI issues which are of vital importance to both the Naval and TMD application areas. It is work which is specific to C^2 research and is unlikely to be carried out in any other context.

SP 2.1.3.1 Techniques for KBS maintenance

Maintenance will become an increasingly important issue for operational knowledge based C^2 systems, in both the Naval and TMD domains. The TDS in particular is now at the stage at which maintenance is becoming a critical issue. This is recognised as a major unsolved problem for the support of operational KBS in general, but it is unlikely that the results of research into the subject in other application areas will be available in time to meet the requirements of the TDS programme.

Category 2.2 : Applied Research, TMD

Budget : £2450K

Projects

SP 2.2.2.1 Specification of KBS for C^2

The problem of adequately specifying of knowledge based systems for the purposes of procurement and validation is generally recognised as one of the major obstacles to their operational deployment in both Naval and TMD applications. It is becoming an increasingly urgent issue as the TDS develops towards operational status and it unlikely that the results of general research in other application areas will be available in time to meet the requirements of the TDS programme.

SP 2.2.2.2 Verification and Validation of safety critical KBS

The problems of verification and validation of KBS are related to the specification issue and research in this area will support SP 2.2.2.1. The *a priori* approach adopted in this project has greater feasibility in the short term than the *a posteriori* approach of SP 2.1.3.3 and can build on existing UK research.

SP 2.2.2.7 Real-time integrated databases

The development of real-time integrated database / knowledgebases is highly critical to the TMD application area and to the enhancement of the functionality of Naval C^2 systems. In view of the particular importance to TMD this project takes precedence over SP 2.1.1.1, which is largely concerned with specific Naval applications, but it does address some of the same issues.

SP 2.2.3.2 Sensor Management **(link project)**

The question of sensor management is critical to the TMD application and the research is special to the C^2 domain.This project brings together HCI and AI issues in the context of resource allocation. To some extent it complements SP 2.1.2.4 on situation assessment, and redresses the lack of Type A projects on resource allocation in category 2.1.2. It also covers real-time design issues and meets the requirement for research in that technology.

SP 2.2.3.4 Development Methods Prototype **(link project)**

The Development Methods Prototype provides the experimental vehicle for the investigation of methodological issues in category 2.2.2, and replaces the TMDD in that role. At the same time, it will investigate a situation assessment application in the TMD domain.

SP 2.2.3.5 Hybrid Approach to Data Fusion

Research into hybrid approaches to data fusion is not immediately critical to the TDS trials programme, since the architecture of the TDS is already defined. However, it is likely that future versions will need to combine KBS with algorithmic techniques. This approach must be seen as critical to any work in the TMD domain, where the scale and complexity of the scenarios dictate that algorithmic techniques must be integrated with AI to achieve the required performance and functionality. The issue of hybrid systems is of general interest to KBS research, but in practice the work may be highly specific to C^2 systems, since it will deal with very specialised techniques. For this reason it is considered unlikely that research in other application areas will be able to make a significant impact in the short term.

Category 3 : Enabling Research

Budget : £1400K

Projects

SP 3.1.1.1 Distributed Situation Assessment

The current TDS does not address the issue of distributed operation, but in the future it is likely that C^2 systems in both the Naval and TMD domains will need to have the capability to operate in distributed mode. At present there is very little work addressing the problems of distributed C^2, although UK work in related areas such as air traffic control may provide a useful starting point. The area is technically challenging and for this reason it is important that some research groundwork should be laid at this stage.

SP 3.1.1.2 Co-operative planning aids for C^2

Planning systems are of particular importance to Naval C^2, but are also highly relevant to the TMD application, where there is a need for a dynamic replanning capability. This project recognises the shortcomings of current AI planners and is a direct response to the expressed needs of operations staff. It combines AI and HCI issues and represents a more flexible and robust approach to the conventional techniques addressed in SP 2.1.4.2.

SP 3.1.2.1 Neural networks for data fusion
SP 3.1.2.2 Machine learning for data fusion

Both of these projects are concerned with radically different, long-term technical approaches to data fusion. However, both techniques have a high potential pay-off for both Naval and TMD C^2 if they prove to be feasible. There is some UK capability in both areas on which to build, and both can be pursued as low-level exploratory research at University rates in the short term.

SP 3.1.2.3 Formal Methods

This project addresses the KBS specification issue and provides an alternative perspective to projects 2.2.2.1 and 2.2.2.2. The UK has a particularly strong capability in this area, and there is a substantial body of research within ARE on which to build. For this reason, the potential results / cost return must be seen as high.

Category 4 : Central Support

The central support activities will be required for any programme of research and are therefore included in the costing of the Type A projects.

6.6.2 Type B Projects

Category 1 : TDS Trials Support

Projects

SP 1.1.3 Development of Training for the TDS

Project 1.1.3 is largely a general support activity with a lower technical content than the other projects in this category, and must be seen as less relevant in the context of a research programme. In view of the budget limitations, therefore, it is excluded from the Type A list.

Category 2.1 : Applied Research, Naval

SP 2.1.1.1 Database / Knowledge base interfacing

Research into database interfacing is not essential to the TDS trials programme, and is of secondary importance to the EnFun objective at this stage. Real-time integrated databases / knowledge bases are likely to become very important to the TMD programme, but are addressed by project 2.2.2.7.

SP 2.1.1.4 Methods and Tools for task analysis

Some techniques already exist for the analysis of task boundaries in knowledge based systems. They have a number of shortcomings, but are probably usable for the purposes of the TDS evaluation trials. The research issues in this area are not unique to C^2 systems, and it may therefore be possible to capitalise on related research in other areas.

SP 2.1.1.5 Optimise HCI design for Tactical Picture Displays

Considerable work has already been done by ARE on the design of displays for data fusion and situation assessment systems. There are still some remaining areas of concern, particularly in the display of uncertainty, but they are lower priority and are, to some extent, covered by SP 2.1.2.4 on HCI for situation assessment.

SP 2.1.1.6 Operator interaction with the TDS

This project concerns a number of issues which are special to Naval C^2. However, they cannot be seen as critical at this stage and are, to some extent, covered by SP 2.1.2.4 on HCI for situation assessment.

SP 2.1.2.2 Enhanced resource allocation Prototype

See SP 2.1.2.1.

SP 2.1.2.3 Enhanced TDS by concurrent processing

Pending the completion of project 1.1.1, it is not yet clear whether a multi-processor architecture will be necessary to achieve the performance targets of the TDS, and the evaluation trials will use the current single processor architecture. Concurrent processing is likely to be required for the TMD application, but is not critical to the next phase of the research programme. In view of the high level of general research activity in this area, it would be more appropriate to wait until the requirement has been better defined before including this project in the research programme.

SP 2.1.3.2 Techniques for knowledge acquisition

The TDS uses a well defined KBS architecture, and current methods of knowledge acquisition are probably adequate for the current programme of enhancement and evaluation. More powerful alternative techniques may be required in the future, as new knowledge representation formalisms are developed to handle spatial and temporal aspects. However, they are not critical at this stage, and should not be included in the research programme until some progress has been made in the knowledge representation projects themselves, such as SP 2.1.2.1 and SP 2.2.3.2.

SP 2.1.3.3 Methods and tools for KBS validation

The validation of knowledge based systems is an important issue and presents a major technical barrier to their operational deployment. However, of the two approaches to validation, the *a posteriori* techniques addressed in this project are already being investigated by ARE, and for this reason the emphasis is placed on the a priori techniques of project 2.2.2.2.

SP 2.1.3.4 Techniques for explanation in situation assessment

Explanation facilities are increasingly being recognised as an important supporting function of knowledge based systems. However, they cannot be seen as a critical issue at this stage, in either Naval or TMD applications.

SP 2.1.4.1 KBS-enhanced HCI

KBS enhanced HCI is not required for the TDS trials programme. It may become an important feature of future versions, but in the short term must be regarded as lower priority than other HCI issues. In the meantime, it is an active area of general research, and it is likely that in time the results of that research will be applicable to the C^2 domain.

SP 2.1.4.2 KBS planners for resource allocation in Naval C^2

This project would extend current AI/KBS research on planning and apply it to the Naval domain. However, it is not directly related to the present TDS developments. In the longer term it may be superceded by general research in AI planning, and by the co-operative approach to planning which is explored in SP 3.1.1.2.

Category 2.2 : Applied Research, TMD

Projects

SP 2.2.1.1 Evaluate and Assess the TMDD
SP 2.2.1.2 Integrated Data Fusion using the TMDD
SP 2.2.1.3 Incorporation of Sit. Ass. and Res. Alloc. in the TMDD
SP 2.2.1.4 Integrate discrimination into TMDD

All projects in Category 2.2.1 (Laboratory Enhancements to the TMDD), are currently rated as Type B in view of the uncertainty concerning the TMD Demonstrator.

SP 2.2.2.3 Robust Architectures for KBS

The question of robustness is important to the deployment of operational KBS, but the problem may be subsumed by other developments arising from the work on scalability (SP 1.1.1) and maintenance (SP 2.1.3.1). The subject is not specific to C^2 applications and there is no special UK capability on which to build.

SP 2.2.2.4 Operational Adaptivity of KBS

Operational adaptivity will similarly be important in the longer term. In the short term the problem is addressed to some extent by SP 2.1.3.1 on KB maintenance. The subject is not specific to C^2, and there is no special UK capability on which to build.

SP 2.2.2.5 Integrating Knowledge Representations

At this stage, research into the integration of alternative forms of knowledge representation is viewed as secondary to the development of those formalisms in application projects such as SP 2.1.2.1, SP 2.2.3.1 and SP 2.2.3.2.

SP 2.2.2.6 Validation of KBS-based on non-expert knowledge

This project is not immediately critical to the Naval domain, where there is access to relevant expertise. It is likely to become critical in the TMD domain in the longer term, but must await some initial prototype development work on TMD applications before its significance can be fully assessed.

SP 2.2.3.1 Adaptive Preferential defence
SP 2.2.3.3 Intention prediction of intelligently manoeuvering objects

Both of these projects address issues which are important to TMD and the Enhanced Functionality of Naval systems. However, they are viewed as being longer term objectives, compared with the more immediate requirements for sensor management. The technical areas are difficult and there is no special UK capability in either area on which to build. Nevertheless, they are both concerned with issues which are special to C^2 systems and in view of the technical problems, should be included at an early stage in any subsequent programme.

Category 3 : Enabling Research

Projects

SP 3.1.2.4 Intelligent training systems

In the longer term, intelligent training systems may be particularly useful for in-service training of Naval personnel on C^2 systems. However, they are not critical to the deployment of the current TDS and must be regarded as lower priority in the short term, relative to other HCI problems. In the TMD domain, training issues must also be seen as secondary until some progress has been made on the implementation of practical prototype systems.

SP 3.1.2.5 Genetic Algorithms for C^2
SP 3.1.2.6 Machine Learning of temporal patterns for C^2

Both of these projects address specific approaches to the design of adaptive C^2 systems which appear to hold some promise in the longer term. However, they are both in an embryonic stage of research and at present there is insufficient evidence of their utility to justify their inclusion in the programme. Both topics are the subject of considerable general research interest, and it would be more appropriate to monitor the developments in other areas before committing to research into their value to C^2.

7. PROGRAMME PLAN

This section summarises information on effort, costs, dependencies and timings for SANDERLING projects, and presents an outline programme plan for Type A projects. Section 7.1 is a summary and interpretation of effort and other costs in the research programme. Section 7.2 shows the major project dependencies and milestones for Type A projects. Section 7.3 shows the timetable relationship for all Type A projects. Finally, Section 7.4 presents resource profile histograms showing the approximate number of people to be employed on the research programme in each month.

7.1 Effort and Costs

7.1.1 Effort and Cost Tables

This section presents a number of tables summarising the effort and other costs proposed for each project.

Effort and Cost Table 1 summarises the effort and other costs by project category and technology stream for all of the proposed projects.

Effort and Cost Table 2 is in similar format to Cost Table 1, but summarises the effort and other costs for Type A SANDERLING projects only.

Effort and Cost Table 3 shows the breakdown of effort and other costs for each of the Type A SANDERLING projects.

Each of the projects is categorised in the same way as Annex C1 and Annex C2 :

Project Category 1 :	TDS Support (Naval)
Project Category 2.1 :	Applied Research (Naval)
Project Category 2.2 :	Applied Research (TMD)
Project Category 3 :	Enabling Research (Naval and TMD)
Project Category 4 :	Central Support (Naval and TMD)

For further information on these project categories, see Section 3.2 of this document.

7.1.2 Assumptions

Several assumptions have been made in compiling these tables:

- A man year of effort has been calculated at an average cost of £80K per annum, in line with recent ARE estimates. This is perhaps optimistic and may be too low for some projects requiring a high proportion of senior staff. A reduced figure of £40K pa per person has been used for university staff where they are expected to be working on a project. Where a university input is envisaged on a project, this has been indicated.

- No allowance for inflation or expected increases over the lifetime of the research programme has been made in these costings.
- Other costs have been estimated on the basis purchasing of new hardware and software in order to do the work in the required time period. In some cases (eg. if ARE do the work), these resources already exist.
- No allowance for other expenses (e.g. travel subsistence, printing, computer media, presentation material) has been included in these cost estimates.
- The calculation of percentage distributions across technical streams and project categories has been based on the manning costs only.
- All manning figures are in years.
- All figures are approximate and for budgetary purposes only.

7.1.3 Interpretation

The following key points on programme effort and costs arise from an interpretation of the tables:

- The total manning cost of all proposed projects is £14,700K.
- The total manning cost of the Type A projects is £6,960K.
- The division of effort between Naval and TMD-related, Type A projects is 50.6% Naval and 49.4% TMD. Naval related effort has been calculated as : effort in Project Category 1 + effort in Project Category 2.1 + 0.5 x (effort in Project Categories 3 and 4).
- The distribution of effort across the technology streams for the Type A projects is different to that for the whole programme. The distribution for the Type A projects reflects the input received from ARE and SDIO described in Section 2.5. Development Methods has a somewhat higher proportion of effort than originally expected. However, it should be noted that the Development Methods Prototype (SP2.2.3.4) will also cover issues of Knowledge Representation and Manipulation.
- Approximately equal effort in each technical stream is distributed between Naval and TMD based projects, with the exception of HCI work, which is primarily based on Naval projects.

Project Category	Manning	% of Total by Project Cat.	Other Costs	HWare	Real Time AI	HCI	DB/KB Interface	Know. Repn.	Methods	Other
1	8.5	4.6%	164K	2	2	4			0.5	
2.1	57.5	31.3%	690K	4		21	5	11.5	16.5	
2.2	81.25	44.2%	580K	19	1.75	12.5	12	15.5	20.5	
3	30.5(14*)	14.7%	260K	6.25(6*)	3.75	7		3.5	10(8*)	
4	9.5	5.2%	5K							9.5
Total	**187.25 (14*)**	**100%**	**1699K**	**31.25 (6*)**	**7.5**	**44.5**	**17**	**30.5**	**47 (8*)**	**9.5**
% of Total Manning Cost	**100%**	-	-	**16.2%**	**4.1%**	**24.2%**	**9.2%**	**16.6%**	**24.5%**	**5.2%**

Effort and Costs Table 1 - Summary of Effort and Costs by Project Category and Technical Stream for the Whole Sanderling Programme

Notes:

1) The percentages calculated above have been based on the manning costs only, and have not ascribed other costs to particular technology streams as yet. The figures are in man years, each costed at £80K, except for those indicated by a *, which have been costed at £60K (the assumption being that the work would be shared between industry costed at £80K per man year and academia costed at £40K per man year). Thus the total manning cost of the programme is 173.25x80+14x60=14,700K, and the percentages shown have been calculated similarly, hence for Methods 39x80+8x60/14,700=0.2448

2) Category 4 projects (Central Support) require effort which lies outside the main technology streams (e.g. in scenario generation). This has been treated as "other" effort in the tables.

Project Category	Manning	% of Total by Project Cat.	Other Costs	HWare	Real Time AI	HCI	DB/KB Interface	Know. Repn.	Methods	Other
1	4.5	**5.2%**	119K	2	2				0.5	
2.1	25.5	**29.3%**	212K			11	2	3	9.5	
2.2	29.0	**33.3%**	310K	5	0.5	3	4	4	12.5	
3	20.5(8*)	**21.3%**	170K	3.25(3*)	3.75	3		3.5	7(5*)	
4	9.5	**10.9%**	5K							9.5
Total	**89(8*)**	**100%**	**816K**	**10.25 (3*)**	**6.25**	**17**	**6**	**10.5**	**29.5 (5*)**	**9.5**
% of Total Manning Cost	**100%**	-	-	**10.9%**	**7.2%**	**19.5%**	**6.9%**	**12.1%**	**32.5%**	**10.9%**

Effort and Costs Table 2 - Summary of Effort and Costs by Project Category and Technical Stream for Type A Projects

Note: Percentages have been calculated using a similar method to that used in Costs and Effort Table 1

Project	Total Manning	Other Costs	HWare	Real Time Sys. Design	HCI	DB/KB Interface	Know. Repn.	Methods	Others
1.1.1	2	62K	0.75	0.75				0.5	
1.1.2	2.5	57K	1.25	1.25					
2.1.1.2	2	30K						2	
2.1.1.3	1.5							1.5	
2.1.1.7	3				3				
2.1.1.8	2	5K						2	
2.1.2.1	7	40K			2	2	3		
2.1.2.4	6	77K			6				
2.1.3.1	4	60K						4	
2.2.2.1	2.5	30K						2.5	
2.2.2.2	6	20K						6	
2.2.2.7	3	40K				3			
2.2.3.2	8.5	90K		0.5	3	1	4		
2.2.3.4	4	30K						4	
2.2.3.5	5	60K	5						
3.1.1.1	5	50K	0.25	3.75	1				
3.1.1.2	5.5	40K			2		3.5		
3.1.2.1	3 *	40K	3 *						
3.1.2.2	3 *	40K						3 *	
3.1.2.3	4(2*)							4(2*)	
4.1.1.1	2								2
4.1.1.2	4.5								4.5
4.1.1.7	3								3
Total	**89 (8*)**	**771K**	**10.25(3*)**	**6.25**	**17**	**6**	**10.5**	**29.5(5*)**	**9.5**

Effort and Costs Table 3 - Summary of Effort and Costs for Individual Type A Projects

Note: See Table 1 for explanation of *

7.2 Dependencies

This section addresses the dependencies and relationships between the Type A projects.

7.2.1 Project Dependency Chart

Dependency Chart 1 shows which Type A projects are dependent on which others and their approximate start times.

Projects are represented by rectangular boxes, with the start date written at the top left hand corner. Some SANDERLING projects have been "split" into phases. This is a result of introducing the appropriate milestones and dependencies. For example, SP2.1.1.2 on KBS Performance and Competence Metrics can be seen to have three phases. The first phase is when the production of the first set of performance metrics and evaluation software will be built. This will be used as input to SP2.1.1.3, SP2.1.1.7, SP1.1.2, etc. The second phase will of SP2.1.1.2 will continue from this milestone, but with the inclusion of the input from the TDS Version 1 Phase 3. Phase 2 will end with the commencement of the sea trials. This will have an effect on the final phase of the project, which then continues from that point. These phases should provide an opportunity for the evaluation of the project (and the programme) progress. The Phase of a project is indicated in parentheses after the title e.g. KBS Performance and Competence Metrics (2), indicates Phase 2 of the project SP2.1.1.2.

Milestones are represented by boxes with rounded corners (e.g. Start, End of Research Programme).

Dependencies are represented by lines. The project/milestone to the right-hand end of a line depends on the project/milestone on the left-hand end for input.

Critical paths are represented by the tasks, milestones and project dependency lines which have been given a heavier typeface (e.g. the path through SP2.2.2.3.4 on the specification of KBS for Command and Control applications through the first version of the Development Methods Prototype, on to SP2.2.3.4 the Development Methods Prototype (2) and finally SP4.1.1.1. The Specification of an advanced Battle Management Prototype). The identification of a critical path is primarily used as an aid to project management; those projects on a critical path are those whose timings allow for no "slack".

7.2.2 Assumptions

The rationale underlying the timings and dependencies on the chart is as follows :

- Certain projects are required to start as soon as possible as part of ARE's ongoing research programme (e.g. SP2.1.1.2 KBS Performance and Competence Metrics). Similarly, SDIO have identified some areas of work as requiring attention as soon as possible (e.g. SP2.2.2.2 Specification and Validation of Safety Critical KBS).

- Some projects will provide input to other projects, and as such will need to be started as soon as possible in the research programme (e.g. SP2.2.2.1 Specification of KBS for Command and Control Applications).

- Some projects will rely on work outside the research programme for input, or are related to other activities (e.g. SP2.1.1.7 Validation of the TDS HCI requires the TDS Version 1 Phase 3 to have been delivered, and SP4.1.1.7 on the TDS Trials data processing will need to begin at the same time as the sea trials).

- Some projects have a very close relationship and will need to proceed in parallel (e.g. SP2.2.2.1 Specification of KBS for Command and Control Applications, SP2.2.2.2 Verification and Validation of Safety Critical KBS and SP2.2.3.4 Development Methods Prototype all contribute to the First Version of the Development Methods Prototype).

- Projects which are not directly dependent on other factors should begin as soon as possible within the research programme.

- The use of this dependency chart (and the timeline chart shown in the next section) are a first step towards generating a programme management plan. Once individual projects have been agreed, a more detailed analysis should be performed with a greater number of milestones and more detailed project dependencies. The charts presented here are intended to show a series of linked projects forming the basic structure of the proposed research programme.

7.2.3 Interpretation

Some general observations can be made from the dependency chart.

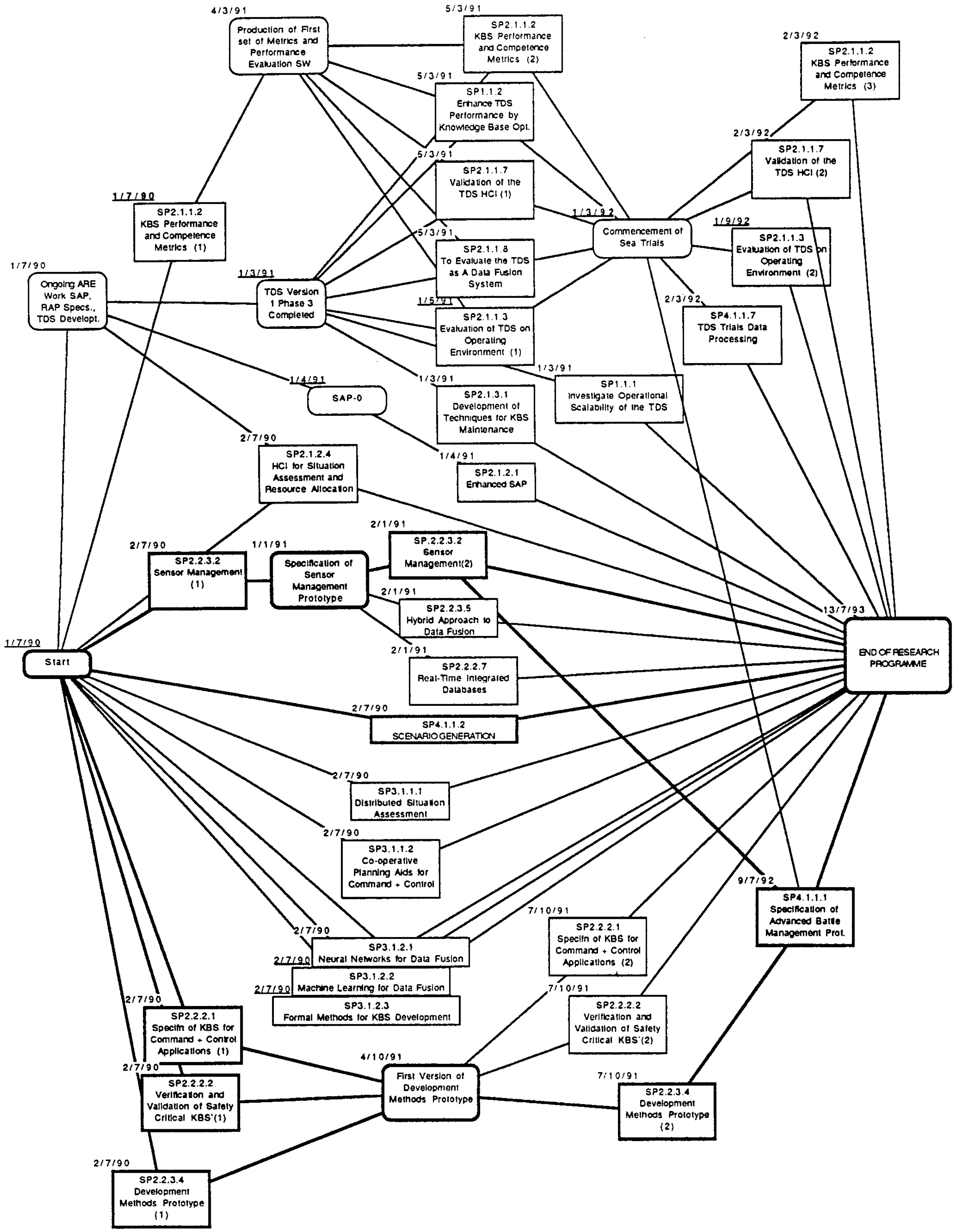
Most SANDERLING projects fall into one of the following groups:

- SP2.2.2.1 Specification of KBS for Command and Control Applications, SP2.2.2.2 Verification and Validation of Safety Critical KBS, and SP2.2.3.4 Development Methods Prototype form a group in their first (and to a lesser extent second) phases. The Development Methods Prototype will be a means of implementing the results of the research in the other two projects.

- The projects SP2.2.3.2 Sensor Management, SP2.2.3.5 Hybrid Approach to Data Fusion, and SP2.2.3.7 Real-Time Integrated Databases form a group of TMD-related application projects.

- These first two groups will pool their results in SP4.1.1.1 Specification of an Advanced Battle Management Prototype.

- The projects SP2.1.2.4 HCI for Situation Assessment and Resource Allocation, and SP2.1.2.1 Enhanced Situation Assessment Prototype form a group in their common application domain of Naval Situation Assessment.



Dependency Chart 1 : Earliest Start for Type A SANDERLING Projects

- The remaining SANDERLING projects in category 2.1 form a group of TDS application-related projects, and as such all have a number of common features and dependencies : reliance on the TDS Version 1 Phase 3, and providing input to and receiving output from the sea trials.

- Each of the above groups contain a **link** projects which the other projects in that group will have a strong dependency on. These **link** projects are SP2.2.3.4, SP2.2.3.2, SP2.1.2.4 and SP2.1.1.2 and are discussed in more detail in Section 6.6.1.

- The enabling technology projects i.e.. SP3.1.1.1 Distributed Situation Assessment, SP3.1.1.2 Co-operative Planning Aids for Command and Control, SP3.1.2.1 Neural Networks for Data Fusion, SP 3.1.2.2 Machine Learning for Data Fusion, and SP3.1.2.3 Formal Methods for KBS Development form a group in that they can proceed independently of each other and the other SANDERLING projects.

- The one exception to the "grouping" of projects is SP4.1.1.2 on Scenario Generation. This project can expect to have the greatest number of interactions with other projects in the programme, and as such cannot be ascribed to any one group.

Three main critical paths have been identified as:

- SP4.1.1.2 Scenario Generation.

- SP2.2.3.2 Sensor Management leading to SP 4.1.1.1 Specification of an Advanced Battle Management Prototype.

- SP2.2.3.4 Development Methods Prototype (together with the first phases of SP2.2.2.1 and SP2.2.2.2), which again leads to SP4.1.1.1.

As stated above, the identification of a critical path means that those projects on it must begin and finish according to schedule for the work to be completed within the allotted time frame of the research programme.

As well as the individual project dependencies outlined above, there are a number of projects which will share a common technology base. There will need to be a mechanism to ensure there is a good exchange of information between these projects. The relationships can be seen in terms of the original technology streams:

- SP2.1.1.2, SP2.1.1.3, SP2.1.3.1, SP2.2.2.1, SP2.2.2.1, SP2.2.3.4 and SP3.1.2.3 all have a strong Development Methods content.

- SP2.1.2.1, SP2.2.3.2, SP3.1.1.2, all have a strong Knowledge Representation content.

- SP2.1.2.1 and SP2.2.2.7 have a strong Database/Knowledge Base Interaction content.

- SP2.1.2.4 will produce results relevant to all the other Human Computer Interaction research components, which are not related directly to the experimental evaluation of the TDS, i.e. SP2.1.2.1, SP2.2.3.2, SP3.1.1.1 and SP3.1.1.2.

- SP1.1.1, SP1.1.2 and SP2.2.3.5 all have a significant Hardware Architectures component, and the first two also have significant effort in real time systems design.

7.3 Timecharts

This section presents the project timeline chart for Type A projects. It is produced from the project dependency chart in Section 7.2.

7.3.1 Timeline Chart

Timeline Chart 1 shows the length of time expected to be occupied by each project within the research programme, taken to run from 1/7/90 to 13/7/93. It also indicates the available "slack" time for a project or milestone, i.e. the amount of time by which a project or milestone can slip without any other dependent project or milestone being affected.

Actual Time to be taken by each project is represented by the length of the white bar.

Slack Time is indicated by the grey shaded bar for a particular project or milestone.

Milestones are indicated by a black diamond.

7.3.2 Assumptions

The assumptions made in constructing this chart are the same as those for the Project Dependency Chart in Section 7.2.2.

7.3.3 Interpretation

The following points should be noted:

- The amount of slack available in projects which are running in the first half of the programme is minimal. This is due to the need to produce results which can be coordinated with other activity (e.g. experimental evaluation must be completed before commencement of sea trials), together with achieving milestones which will be used to determine the success of the work to date (e.g. the first version of the development methods prototype).

- Some slack time has been allowed in key external milestones i.e. The TDS Version 1 Phase 3, the SAP-0 and the commencement of sea trials.

- Since there is slack time towards the end of the programme, this schedule gives the research programme the best chance of finishing on time.

7.4 Resource Profiles

This section presents information relating the distribution of manpower resources to different scheduling strategies for the programme. In order to explore alternative resource loadings, two scheduling strategies were chosen. An "Earliest Start Schedule" (i.e. projects begin as soon as possible in the programme), and an "Adjusted Start Schedule" (i.e. project start dates are adjusted to give a more even resource profile across the programme) profile. The histograms show the cumulative resource loading throughout the programme (Resource Profile Charts 1 & 2) for each of these scheduling strategies.

7.4.1 Resource Profile Charts

The Resource Profile Charts are histograms showing the expected number of people to be employed during any month of the proposed research programme. For example, in Resource Profile Chart 1, there would be 40 people expected to be working on the research programme as a whole in the 10th month since the beginning (i.e. May 1991 assuming an August 1990 start date).

7.4.2 Assumptions

The assumptions made in constructing these charts are the same as those used previously in Section 7.2.2, with the difference being:

For the Earliest Start Schedule it is assumed that:

- Projects which are not directly dependent on other factors should begin as soon as possible within the research programme.

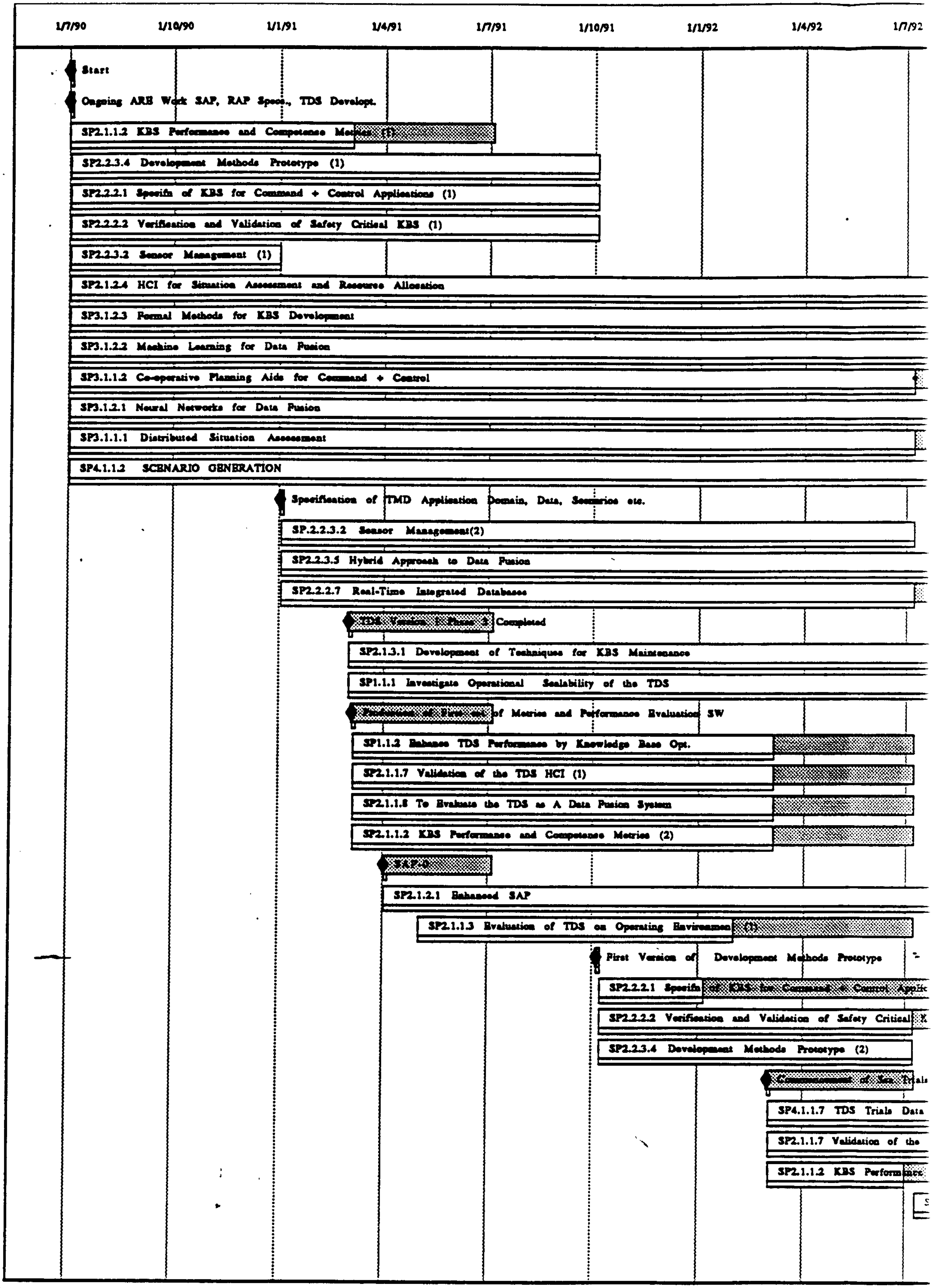
For the Adjusted Start Schedule it is assumed that:

- Projects which are not directly dependent on other factors are distributed across the time frame of the programme in an attempt to ensure as even a distribution of effort as possible.

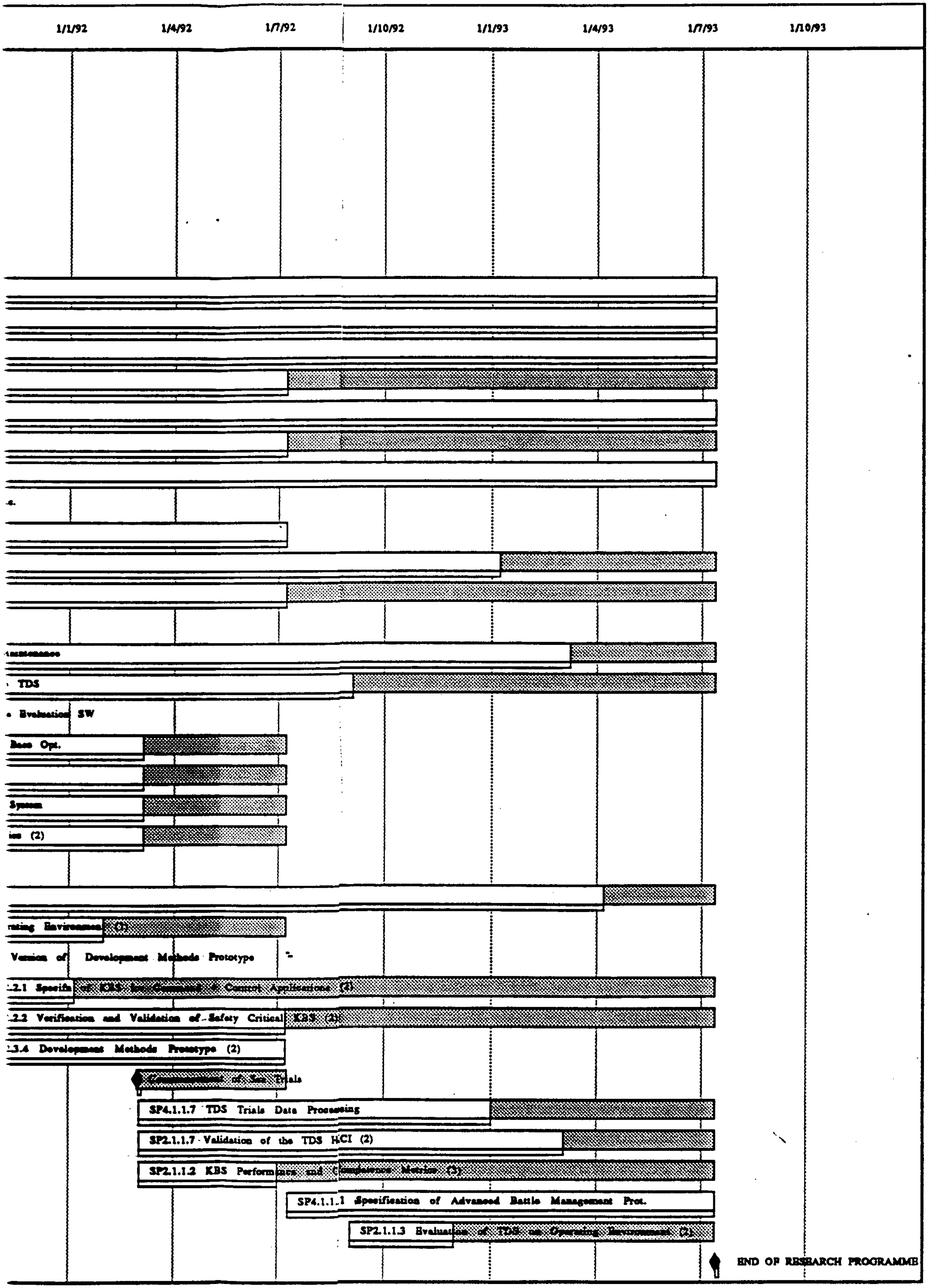
N.B. The charts presented in Sections 7.2 and 7.3 were constructed using the Earliest Start Schedule.

7.4.3 Interpretation

The main feature of the resource profiles is the flatter profile for the Adjusted Start Schedule (Resource Profile Chart 2). This avoids the larger fluctuations in manning levels under the Earliest Start Schedule. It also has the additional benefit of requiring less manpower in the first six months of the research programme (19 as opposed to 24 men). The maximum number of people required at any time under the Earliest Start Schedule will be 47, whereas under the Adjusted Start Schedule, this figure is reduced to 43. It should be noted that if a totally flat profile were possible over the three years, this would mean approximately 30 people fully employed for the entire length of the research programme.



Timeline Chart 1 - Timelines for Type A SANDERLING



Timelines for Type A SANDERLING Projects in Dependency Chart 1

In spite of these characteristics, the Earliest Start Schedule is recommended for the following reasons:

- The Adjusted Start Schedule has the benefit of fewer people working on the programme in the first six months. This is offset by the fact that ARE already have at least 12 people who will continue to work on the research programme. The number of new people required to work on the programme will therefore not be as great as indicated on the Resource Profile Charts.

- The Earliest Start Schedule offers more slack time in the programme as a whole. Since we can expect there to be some slippage in a programme of this size, the maximum availibility of slack and an early planned start is a strong advantage. The Earliest Start Schedule will therefore offer more flexibility.

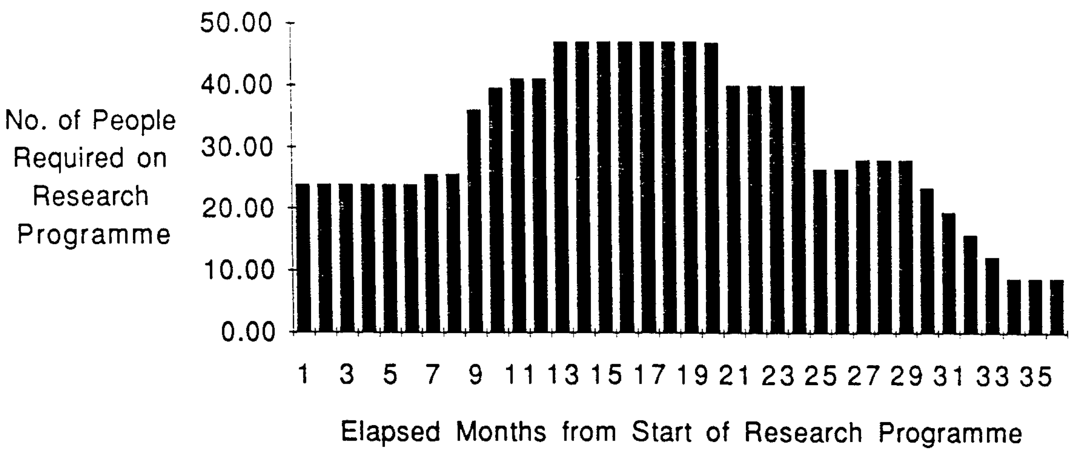
- It will be cheaper for more people to be employed in the earlier stages of the programme (without overloading management resources or contradicting project dependencies), this should be cheaper, assuming that the rise labour costing rates will be at least in line with inflation throughout the course of the programme.

7.5 Conclusions

This section has summarised the effort and costs of the proposed research programme, and has shown the main characteristics of a programme comprised of the Type A projects. This information is a first step towards generating a programme management plan. Once individual projects have been agreed, more analysis would then be required to do this task, with a greater number of milestones and more detailed project dependencies. The charts presented here are intended to show a series of linked projects forming the basic structure of the proposed research programme.

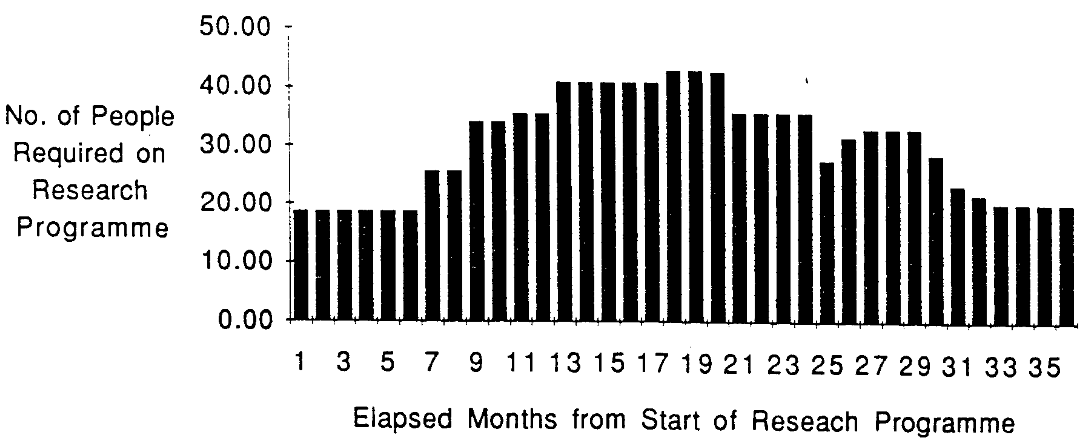
Two scheduling strategies were presented, an Earliest Start Schedule where projects begin as soon as they can, and an Adjusted Start Schedule where projects are scheduled in order to obtain as even a resource profile as possible. The Earliest Start Schedule is recommended.

Resource Profile for Earliest Start Schedule of Sanderling Projects



Resource Profile Chart 1

Resource Profile for Adjusted Start Schedule of Sanderling Projects



Resource Profile Chart 2

8. RECOMMENDATIONS

As a result of the SANDERLING study reported on in this document we have a number of recommendations on the way forward. These are summarised as follows:

1. Early action is needed to adopt and initiate the research programme;
2. The recommended short list of selected projects should be used initially;
3. Projects should be carried out as packaged groups;
4. A TMD 'Development Methods' package should be initiated early;
5. The specification of a future BMC^2D should be part of the programme;
6. Adequate allowance should be made for management of the programme;
7. A phased start to the programme would give an acceptable distribution of effort;
8. Central projects such as scenario generation assessment should be started early.

8.1 Initiate Research Programme

It is recommended that early action should be taken to adopt and initiate the research programme. There are two main reasons for this recommendation. Firstly, the TDS programme requires immediate commencement of many of the projects that support ARE's on-going research work; in particular those projects linked to trials. Secondly, allowing for contracting lead times the earliest date for projects to start is likely to be August 1990. Any later start begins to put pressure on the three year programme because of the firm end date in mid-1993 (eg. dependencies between consecutive projects such as those on metrics would result in this work stretching beyond the end date).

8.2 Use Short List

To enable an early start we recommend that the proposed short list of selected projects (Type A) be used, at least initially. This list provides SDIO/ARE with an evaluated and reviewed set of priority projects. The Annex C2 descriptions can be converted quickly into RFPs/ITTs and the contracting process initiated. Additionally, projects can be selected and set up so that they do not imply a full three year commitment by ARE/SDIO and allow for a review of the programme at appropriate intervals.

8.3 Packages of Projects

There are 23 short listed Type A projects. Among many of them there is a degree of linkage and inter-dependency. We recommend that these projects be packaged into groups and that the packages are delegated to single industrial contractors/consortia (eg. scalability & optimisation; sensor management & database/KBS interfaces). There are four main reasons for this recommendation. Firstly, there is likely to be technical advantage in one organisation carrying out a number of linked projects. Secondly, there are likely to be cost advantages by avoiding duplication and unnecessary liaison. Thirdly, inter-company confidentiality issues etc are minimised; and finally, such packaging will reduce the management overhead on ARE/SDIO/SDIPO.

8.4 TMD Development Methods Package

A set of projects that can be started initially are those that address the issue of development methods in the context of TMD/SDI. Projects on KBS specification, and verification and validation link closely to the development of a TMD prototype. The prototype will provide an early example of the use of KBS to support a TMD application. It will also complement the RAE work by focussing on a different but related problem to that currently under investigation (eg. reactive situation assessment). Most importantly it will provide the application-oriented project which the development methods research can use.

8.5 Advanced BMC^{2}D

The programme should include the concept of an advanced Battle Management and C^2 Demonstrator (BMC^{2}D). This would provide a focus for many SANDERLING research projects and a clear way forward at the end of the programme. The outline specification and requirements of a future BMC^{2}D should be included in the programme but detailed design and implementation would be a follow-on activity. The BMC^{2}D would enable the results of more recent work than that embedded in the Naval data fusion TDS to be developed into an engineered demonstrator that is applicable to SDI/TMD. It would also provide a means of integrating other work in the UK on SDI/TMD battle management and command and control.

8.6 Management of Programme

There is a planned budget of £7m and approximately 20 projects with a range of tightly defined objectives. Although this programme will not be large in total value compared to national and international KBS research programmes, it is essential its success that adequate provision is made to manage and evaluate the programme efficiently. This will include tasks such as: planning, control and direction of individual research projects, contractor management, liaison with UK and US government agencies, financial monitoring and control and strategy and organisation of the programme. Advice from those involved in managing KBS research programmes suggests that programme management effort needs to be from 7 to 14% of the total budget and is a significant element in achieving value from a research programme of this nature.

8.7 Programme Timing

The recommended scheduling for the programme is based on Type A projects commencing as soon as dependencies allow. Although this will mean starting a large number of projects at the beginning of the programme, the resulting 'cliff' is likely to be less severe than it appears because it contains the continuation of some of ARE's existing projects. Furthermore, this approach will introduce more slack time into the programme, offering more flexibility for project management.

8.8 Start Central Projects

The programme includes a number of central support projects. A number of these will need to start at the beginning of the project. These will clearly include programme management, which will need to draw up and instigate a management plan immediately. Another priority is to identify the requirements for scenario generation and data input and establish the degree to which available facilities can be used. This should done immediately so that the impact on other research projects can be assessed at an early stage in the programme. Work to specify the requirements for HCI trials facilities and TDS trails data processing should also start early in the programme.

ANNEX C1 : Table of Sanderling Projects

1. Category 1 - TDS Deployment

Serial No	Description	Type	ARE Nos	Technical topics	Time	Effort	Manpower Cost (£K)	Other Costs (£K)
1.1.1	Investigate the operational scalability of the TDS	A	5.8	1.Hardware Archit. Paradigms 2.Dev Methods Robust Archit.	1.5y	2my	160	62
1.1.2	Enhance TDS Performance by KB Optimisation	A	12.1	1.Hardware Archit. Paradigms 2.Real-time Systems	1y	2.5my	200	57
1.1.3	Development of training for the TDS	B	7.1	HCI	3y	4my	320	45

Notes:

- Costs are expressed as a function of manning, each man year is costed at £80k. Resources have not been included.
- For further information on ARE Nos, see the ARE Research Programme Document AXT/23.01.02/90.
- As in Section 7, those man years of effort marked with an * are costed at £60k each (the assumption being that the work would be shared between industry costed at £80k per man year and academia costed at £40k per man year).

2. Category 2 - Applied Research

2.1 Naval

2.1.1 TDP Support

Serial No	Description	Type	ARE Nos	Technical topics	Time	Effort	Manpower Cost (£K)	Other Costs (£K)
2.1.1.1	Investigate database/KBase interfacing techniques	B	3.2,14.1	1.Database/KBase Coupling	1y	2my	160	55
2.1.1.2	Derive KBS performance and competence metrics for the TDS evaluation programme	A	5.1,5.6	1.Dev. Methods Life Cycle Model Validation	2y	2my	160	30
2.1.1.3	Evaluation of the Impact of the TDS on the Operating Environment	A	5.4,5.5	1.HCI	1y	1.5 my	120	-
2.1.1.4	Develop design methods & tools for task analysis	B	5.4,9.2	1.HCI	1y	2my	160	32
2.1.1.5	Optimisation of HCI design for tactical picture displays	B	5.4,5.5 10.4,10.7	1.HCI	1.5y	2.5my	200	52
2.1.1.6	Evaluation of the effects of operator interaction with the TDS	B	5.7	1.HCI	1y	2my	160	10
2.1.1.7	Validation of the TDS HCI	A	5.3,10.1	1.Develop. Methods Validation	2y	3my	240	-
2.1.1.8	To evaluate the TDS as data fusion system	A		1.Develop. Methods Validation 2. HCI	1y	2my	160	5

2.1.2 Laboratory Enhancements

Serial No	Description	Type	ARE Nos	Technical topics	Time	Effort	Manpower Cost (£K)	Other Costs (£K)
2.1.2.1	Enhanced Situation Assessment Prototype	A	1.3	1.Knowledge Rep. Temporal Spatial Modal Reason Uncertainty	2y	7my	560	40
2.1.2.2	Enhanced Resource Allocation prototype	B	1.5	1. Knowledge Rep. Planning 2. Database/Kbase 3. HCI	1.5y	5my	400	40
2.1.2.3	Enhance TDS performance by concurrent processing	B		1.Hardware Archit Paradigms	3y	4my	320	125
2.1.2.4	HCI for Situation Assessment and Resource Allocation	A		1.HCI	3y	6my	480	77

2.1.3 Use Laboratory Prototypes

Serial No	Description	Type	ARE Nos	Technical Topics	Time	Effort	Manpower Cost (£K)	Other Costs (£K)
2.1.3.1	Development of techniques for KBS maintenance	A	2.1,2.4	1.Develop. Methods Maintenance	2y	4my	320	60
2.1.3.2	Investigation of techniques for knowledge acquisition	B	2.7	1.Develop. Methods K. Acquisition	1.5y	3my	240	30
2.1.3.3	Development methods and tools for the *a posteriori* validation of knowledge based systems	B	2.5,2.6	1.Develop.Methods Validation Life Cycle	1.5y	3.5my	280	30
2.1.3.4	Exploration of appropriate techniques for explanation in situation assessment systems	B	9.3	1.HCI Cognitive Issues	2y	2my	160	32

2.1.4 Other Prototypes

Serial No	Description	Type	ARE Nos	Technical Topics	Time	Effort	Manpower Cost (£K)	Other Costs (£K)
2.1.4.1	Exploration of Adaptive Interfaces for Command and Control Systems	B	10.2	1.HCI Modelling Issues	1y	1.5my	120	32
2.1.4.2	KBS for amphibious operations support	B	14.2,14.3	1.Knowledge Rep. Planning	2y	4.5my	360	40

2.2 TMD

2.2.1 Lab Enhancement

Serial No	Description	Type	ARE Nos	Technical topics	Time	Effort	Manpower Cost (£K)	Other Costs (£K)
2.2.1.1	Evaluation and Assessment of the TMDD	B No longer valid	N/A		1.5y	3my	240	32
2.2.1.2	Integrated Data Fusion using the TMDD	B No longer valid	Related to data fusion experiments on TDS	1.H/W A - Paradigms 2. Neural Nets 3. DB/KBS coupling	3y	12my	960	40
2.2.1.3	Incorporation of Situation Assessment and Resource Allocation in the TMDD	B No longer valid	Related to TDS enhancements		2y	10my	800	
2.2.1.4	Integrate Discrimination into TMDD	B No longer valid		SDIO research with RAE	1.5y	2.5my	200	

2.2.2 Use Lab Prototypes

Serial No	Description	Type	ARE Nos	Technical topics	Time	Effort	Manpower Cost (£K)	Other Costs (£K)
2.2.2.1	Specification of KBS for Command and Control Applications	A	2.6-LCM 5.1,5.6 evaluation	1. Dev Methods	1.5y	2.5my	200	30
2.2.2.2	Verification and Validation of 'Safety Critical' KBS	A	2.5 Val 5.1,5.6 evaluation (2..1.4.1)	1. Dev Methods	2y	6my	480	60
2.2.2.3	Investigation in to the Robustness of KBS Architectures	B	(1.1.1.1)	1. Dev Methods	2y	2my	160	-
2.2.2.4	Operational Adaptivity of KBS knowledge bases	B		1. Dev Methods	1y	4my	320	30
2.2.2.5	Integrating Knowledge Representations	B	(2.1,2.2,2.3) 3.3	1. Real Time 2. DB/KBS	0.75y	2.25my	180	30
2.2.2.6	Development of KBS not based on 'Expert' knowledge	B	SDIO interest	1. Dev methods	0.75y	1my	80	-
2.2.2.7	Real-Time Integrated Databases	A	SDIO interest	1. DB/KBS	1.5y	3my	240	40

2.2.3 Stand-alone Prototypes

Serial No	Description	Type	ARE Nos	Technical topics	Time	Effort	Manpower Cost(£K)	Other Cost (£K)
2.2.3.1	Adaptive Preferential Defence	B	React Res All 1.5	1. H/W A - Paradigms 2. RT/Syst Eng 3. KREP 4. HCI	1.5y	8.5my	680	60
2.2.3.2	Sensor Management	A	Dynamic scheduling? (Flypast +)	1. RT/Syst Eng 2. KREP 3. HCI 4. DB/KBS	2y	8.5my	680	90
2.2.3.3	Intention Prediction of Intelligently Manoeuvering Objects	B	Sit Ass R R All	1. KREP 2. HCI 3. DB/KBS 4. Naval (tracking)	2y	7my	560	40
2.2.3.4	Development Methods Prototype	A		1. Develop. Methods	2y	4my	320	30
2.2.3.5	Hybrid Approach toData Fusion	A	TDS Improvements	1. H/W A	2.5y	5my	400	60

3. Category 3 - Enabling Research

3.1 TMD and Naval

3.1.1 Adv Prototypes

Serial No	Description	Type	ARE Nos	Technical Topics	Time	Effort	Manpower Cost (£K)	Other Costs (£K)
3.1.1.1	Distributed Situation Assessment	A	BMC2 Prot 1.7 Extends Sit Ass in TDS/TMDD	1. DAI 2. KREP 3. HCI 4. DB/KBMS -KBMS	2y	5my	400	50
3.1.1.2	Co-operative Planning Aids for Command and Control	A	9.4,10.2,10.5 (1.4,1.5 re-visited)	1. HCI 2. KREP 3. DAI	2y	5.5my	440	40

3.1.2 Other Projects

Serial No	Description	Type	ARE Nos	Technical Topics	Time	Effort	Manpower Cost(£K)	Other Costs (£K)
3.1.2.1	Application of Neural Networks for Data Fusion	A	leads on from existing ARE research	H/W Arch - NNets	3y	3my*	180	40
3.1.2.2	Application of Machine Learning for Data Fusion	A	new research proposal	Dev Methods (ML/KA)	3y	3my*	180	40
3.1.2.3	Application of Formal methods in KBS development	A	leads on from existing ARE research	Dev Methods (Formal Methods)	3y	4my (inc. 2my*)	280	-
3.1.2.4	Intelligent Training systems for Command and Control systems	B	7.2 8.1,8.4 13.1	1.HCI Organisational Issues	1.5y	4my	320	30

3.1.2.5	Genetic algorithms for Command and Control Applications	B		KRep and Dev Methods	3y	3my*	180	30
3.1.2.6	Machine Learning of Temporal Patterns for Command and Control	B		KRep and Dev Methods	3y	3my*	180	30

4. Category 4 - Central Support

4.1 TMD and Naval

Serial No	Description	Type	ARE Nos	Technical Topics	Time	Effort	Manpower Cost (£K)	Other Costs (£K)
4.1.1.1	Specification of Advanced Battle Management Prototype		BMC2 Prot 1.7		1y	2my	160	5
4.1.1.2	Scenario Generation and Data		4.1,4.2,4.3		3y	4.5my	360	
4.1.1.3	Provision of HCI investigation /trials facilities							
4.1.1.4	TDS Facilities management							
4.1.1.5	Programme Co-ordination							
4.1.1.6	Programme Evaluation							
4.1.1.7	TDS Trials Data Processing				1y	3my	240	

The SANDERLING Final Report comprises the following three volumes :

- The **EXECUTIVE SUMMARY** provides an overview and summary of the study, including its conclusions and key findings, but not including specific detail on suggested projects;

- **PARTS A & B** cover the method and direction of the study, and include details of the technology analysis as well as the initial thniking behind the projects;

- **PART C** of the Final Report defines the recommended research programme in some detail. It describes suggested projects (including form, content, cost and resources), overall programme structure and recommendations on how to proceed.

ANNEX C2 : Sanderling Project Descriptions

Table of Contents

Note : The following experiments are no longer under consideration and have been excluded from this Annex :

SP 2.2.1.1	Evaluation and Assessment of the TMDD
SP 2.2.1.2	Integrated Data Fusion using the TMDD
SP 2.2.1.3	Incorporation of Situation Assessment and Resource Allocation into TMD Demonstrator
SP 2.2.1.4	Integrate Discrimination into the TMDD

Introduction

The purpose of this Annex is to present in detail the SANDERLING projects described and evaluated in Part C of the Final Report. In each case sufficient description has been provided to form the basis of an ITT. The structure of each description is as follows:

Sanderling Project Title

Description

Brief description of the project.

Objectives

Objectives which the project should achieve.

Technical Work Involved

Description of the technical work to be carried out by the project. This may consist of a number of work packages associated with different technology streams, eg. Hardware architectures.

Relation to Programme

Any identified dependencies with other parts of either the SANDERLING programme, the TDS or TMD demonstrator activities.

Time and Effort

The proposed effort and timescale for the work described.

Inputs/Assumptions

Any identified inputs or assumptions made when formulating the project descriptions, eg. Availability of TDS Version 1.

Deliverables

List of deliverables the project will produce

Resources

Any resources in addition to effort required, eg workstations, and an estimate of their cost. Specific technical and application skills are listed to assist in targetting suitable organisations or individuals to undertake the project.

SP 1.1.1 Investigate the operational scalability of the TDS

Description

This project will use the performance and competence metrics being developed under SP2.1.1.2 (Derive KBS performance and competence metrics for the TDS evaluation programme) in order to determine the operational scalability of the existing solution to the data fusion problem.

Objectives

The TDS Version 1 Phase 3 will have been developed and tested against a limited range of real world scenarios, with the data used having been subjected to a large amount of pre-processing. In practice, an operational system will need to handle a much broader range of data (e.g. including coastline effects, modelling of jamming techniques etc.) and much higher numbers of more complex tracks. The system must show itself capable of processing this data in a fast, robust and fault tolerant manner. At present there is no practical basis for defining the performance envelope of the system (e.g. graphs of the number of objects/tracks against the time taken to produce each update to the tactical picture display) or for predicting and testing the implications of varying scenario size and complexity. The objectives of this project are:

- To determine the current limits of performance of the TDS Version 1 Phase 3 in terms of the number of tracks and objects it can process correctly in real-time and other criteria as are felt necessary.
- To propose alterations to the hardware and software of TDS Version 1 Phase 3 for extending its performance envelope to deal with scenarios of varying size and complexity envisaged in operational use.
- To analyse the scalability aspects of the sea trials conducted with the TDS.

Technical Work Involved

Overview

Scenarios which will adequately test the TDS Version 1 Phase 3 to see that it matches the current specification (Miles 1989) will have been specified and run under SP2.1.1.2. If the TDS Version 1 Phase 3 meets the specification, then the next step should be to start to examine the limits of TDS Version 1 Phase 3 in terms of the number of tracks and objects it can process within the specification time. Thirdly it will investigate the suitability of a range of options aimed at extending the performance envelope of the system, whilst still using the basic paradigms (serial, non-distributed and blackboard) employed in the TDS Version 1.

Appropriate methods for achieving scalability in the TDS Version 1 Phase 3 cannot be determined until the results of the evaluation phase. The areas which can be anticipated to be important are: the use of memory (primary and secondary), how efficient garbage collection becomes under increased processing loads, and the ability of communication channels to provide the required bandwidths. The ability of the system to continue operating in real-time must be considered, with the identification of where critical points in the processing sequence occur. The quality of output will

also be measured, in terms of the number of false and missed tracks/targets, and the accuracy with which actual tracks and targets are identified. The scenarios, of variable size, will need to be based on real data, ideally derived from the TDS sea trials programme. Recommendations for improving the TDS will be based on the criteria which prove to be the least satisfied in terms of performance. Possible alternative types of recommendation are:

- Hardware enhancements to the TDS (Use of new memory boards, custom built data links, additional processing nodes in the network).
- Development of new procedures for handling critical points in the processing path (e.g. garbage collection, conflict resolution).
- Development of new/adapted knowledge representations and control paradigms with reduced processing overheads.

Research Components

1. Hardware Architectures

The work will acquire and run the scenarios of varying size and complexity on the TDS Version 1 Phase 3. These scenarios will be based on sea trials data. It should specify what the factors affecting the scalability of the TDS are. It will assess the degree of improvement (measured in terms of the number of tracks and objects handled) achievable through the introduction of new hardware components to the TDS. It will also investigate adapting the knowledge representations for extending the ability of the TDS to handle scenarios of varying sizes. Finally it will analyse the results of the sea trials to determine the potential scalability of the TDS for future procurement and deployment.

2. Methods

The work will complement the work done in SP2.1.1.2 and will investigate the KBS architecture and reasoning processes of the TDS with regard to their robustness and fault-tolerance under scenarios of varying size. The research will identify areas where the TDS can be enhanced in order to improve its operational robustness under these conditions.

3. Real-Time AI

This work is an investigation of the degree to which the TDS can be enhanced for real-time processing for scenarios of varying size and complexity. The objectives will be to investigate the compatibility of the TDS architecture for prioritisation of processing, the adoption of a progressive reasoning strategy, and to define any requirements for enhanced garbage collection. Only recommendations on the applicability of these methods will be produced.

Relation to Programme

This project forms part of a series of projects designed to improve the operating capabilities of the TDS Version 1 Phase 3 (SP1.1.2), and is primarily concerned with identifying requirements and problem areas. If techniques for handling larger scale scenarios are developed then they will have a natural impact on the design of all future

modules of the TDS (e.g. SP2.1.2.1, SP2.1.2.2). SP2.1.2.3 on the use of concurrent processing will make use of the evaluation results obtained in the first part of the project, SP3.1.2.1 can also examine the applicability of neural networks and genetic algorithms as ways of improving the speed and accuracy of those tasks where bottlenecks occur in the purely rule-based approach. The range of activities which can be carried out under the hardware architectures component are more cost limited than the software components, given the high capital cost of hardware experiments. Since the TMD application is expected to handle scenarios of much greater size than the Naval application, this work would provide an indication of the ease with which the TDS can be applied to a real world TMD problem.

Time and Effort

Hardware Architectures	0.75 my
Methods	0.5 my
Real Time AI	0.75 my

Total : 2 man years over a 18 month period.

Inputs/Assumptions

The main inputs to this project will be the TDS Version 1 Phase 3 the results of SP2.1.1.2 for evaluating the performance of the TDS, the results of SP1.1.2 on optimisation of the knowledge base for increased processing speed, SP4.1.1.2 to provide scenarios if required, and sea trials data to indicate the scale of problem to be considered. Note that the sea trials are due to take place in the last year of the research programme, thus if there is any slippage then it is unlikely that any input can be obtained from that work.

Deliverables

- Specification of scenarios of varying size and complexity for running on the TDS Version 1 Phase 3. Identification of those aspects of the TDS which will influence its scalability (speed and fidelity of processing, memory use and garbage collection, communication links)

- Analysis of TDS Version 1 Phase 3 performance under varying scenario size and complexity.

- Recommendations on the suitability of real-time AI Techniques for improving TDS performance on scenarios of varying size.

- Recommendations on the possible use of new serial processing hardware for improving TDS performance on scenarios of varying size.

- Recommendations on changes in KBS architecture and processing for improving TDS performance on scenarios of varying size.

- Analysis of the change in TDS performance for variable scale scenarios from introduction of recommended techniques.

- Analysis of data on scalability extracted from sea trials of the TDS.

Resources

Hardware: Workstation £25k, (i.e. access to a TDS programming seat)

New Hardware (memory, CPU boards, custom built communications) £30k

Software: Ada Compiler £7k

Total : £62k

The following skills and experience are central to the success of this project :

- senior staff who have assessed technical system performance on a number of projects;
- specialists with software architectural experience : specifically the hardware / software partitioning of systems;
- skill at implementing a variety of real-time KBS control structures;
- experience of Naval C^2 systems.

SP 1.1.2 Enhance TDS Performance by Knowledge Base Optimisation

Description

This project will increase the operating speed of the TDS Version 1 Phase 3 by focussing attention on the efficiency of the KBS implementation. Account will be taken of the previous and existing work carried out at ARE by John Daniel (Daniel 1989).

Objectives

One of the critical factors for judging the progress of the TDP is the speed of operation of the TDS (Miles 1989a). The main objective of this project is:

- To determine what improvements in operating speed can be obtained through the optimisation of the current KBS implementation (ie. taking a short-term view)

- To perform modifications to the TDS to address performance bottlenecks

The primary concern will be increasing the speed of operation, while retaining functional levels of performance (i.e. accuracy and completeness of output) using the current serially based implementation as used in TDS Version 1 Phase 3 as a baseline from which to conduct the project.

Technical Work Involved

Overview

There are a range of techniques which are available to optimise KBS design for performance, some of which are listed below. Each of these will be investigated on a small subset of the KBS component of the TDS Version 1 Phase 3, and the most promising options selected for a more detailed implementation. The work will also consider techniques for ensuring real-time response capability within the performance constraints imposed by the current hardware architecture and software design of the TDS.

The work involved attempts to directly build upon the TDS Version 1 Phase 3 by the implementation and subsequent evaluation of a set of techniques for increasing the efficiency of KBS operation. Two approaches will be considered: changing the form of the knowledge and changing the control structure under which the knowledge is applied. The impact of any changes on the accuracy of interpretation and its completeness will be compared with results obtained from the TDS Version 1 Phase 3 system.

Research Components

1. Hardware Architectures

The work will consist of three main activities:

a) Benchmarking the speed and efficiency of various factors influencing knowledge base operation. A small subset of the TDS Version 1 Phase 3 (e.g. A specific knowledge source) would be used as the initial application. A number of scenarios will be run on the TDS Version 1 Phase 3, and the contribution of each of the activities involved in the operation of the knowledge source will be recorded (time spent on blackboard before knowledge source invoked, time taken to match with antecedants of each rule, number of times each rule fired, amount of garbage collection performed during knowledge source firing, total elapsed time spent in knowledge source consultation).

b) An initial, practical investigation of techniques for optimising rule-based KBS performance, namely, implementation in a faster serially based language, changing the structure of the rule-base, changing the design of rules e.g. changing the orders of conditions tested in rules, modifying the knowledge representation to obtain faster operation, e.g. using hash tables, changing the control structure for rule invocation, e.g. allowing some rules to fire every cycle and adding an extra level of control to resolve any conflicts. This work would use the knowledge source selected and associated benchmarks developed under (a), together with prototype software implementing each of the above techniques in order to produce results showing the change in each of the benchmark criteria, with emphasis placed on any reduction in total elapsed time. These results will produce a ranking on the optimisation techniques tried.

c) The most promising of the techniques investigated under (b) will then be implemented on a wider scale. Prototype implementation of a technique will take place wherever possible in the TDS Version 1 Phase 3. The scenarios specified under (a) will then be used in combination with the evaluation procedures of SP2.1.1.2 to assess any increase in the operating speed of the TDS Version 1 Phase 3 from the use of these optimisation techniques.

2. Real-Time AI

This component will complement the work being done under (b) and (c) above but pay specific attention to enhancing the TDS Version 1 Phase 3 by modifying the process scheduler (agenda) to deal with the prioritisation of activities in a knowledge source, and by the incorporation of a progressive reasoning strategy.

Relation to Programme

Although the level of success of this project cannot be fully estimated beforehand, it is expected to influence other work aimed at speeding up TDS operation, such as SP2.1.2.3. on concurrent processing. Other projects which focus on the TDS Version 1 KBS elements may well be influenced by the results of this project, such as SP2.1.3.1 on knowledge base maintenance, and SP2.1.3.3 on KBS validation (e.g. if a new form of knowledge representation is found which is more efficient, it may also be hard to update, understand or maintain consistency of the knowledge base

given that representation). If any techniques show consistent improvements in operating speed, then they should be considered at the design stage for all future KBS modules and prototypes built under the research programme.

Time and Effort

Hardware Architectures	1.25 my
Real Time AI	1.25 my
Total	2.5 man years over a 12 month period.

Inputs/Assumptions

The main inputs to this project will be the TDS Version 1 Phase 3, and the latest set of benchmarks produced by ARE, SP4.1.1.2 for scenario generation and SP2.1.1.2. to provide the performance metrics and software for evaluation. If none of the options initially investigated under (b) prove to be of sufficient interest, work in this project should not be pursued beyond that point.

Deliverables

- Specification of scenarios and criteria for benchmarking the operation of a specific knowledge source of the TDS Version 1 Phase 3. Results of the benchmark runs using these scenarios.
- Software prototypes incorporating a range of techniques for optimising the operation of the knowledge source selected. Results from running the benchmark scenarios using these prototypes. Recommendations for optimisation techniques for extended implementation throughout the TDS Version 1 Phase 3.
- Software prototype enhancement to the TDS Version 1 Phase 3, incorporating recommended techniques improving for KBS speed of operation. Results from running the benchmark scenarios on these prototypes. Analysis of any improvements in operating speed achieved from the changes implemented.
- Recommendations for future KBS building practice to consider optimal implementation considerations at the design stage.

Resources

Hardware :	2 Workstations £50k (i.e. access to 2 TDS programming seats)
Software :	Ada Compiler £7k
Total :	£57k

The following skills and experience are central to the success of this project :

- senior staff with practical benchmarking and performance evaluation experience
- knowledge engineering staff with specific expertise at using different representation techniques to implement a variety of architectural solutions in a non-academic environment
- staff with KBS systems design and implementation experience

SP 1.1.3 Development of Training for the TDS

Description

This project will prepare the necessary lecture notes, visual aids, tests of competence, and computer based training material for training prospective users and operators of the TDS. Users are here defined as the officers on board a ship who use the output of the TDS to make high-level decisions on the running of the ship, and operators are defined as those men who interact directly with the TDS, passing on the output as appropriate to the users.

Objectives

The TDS is nearing both shore based trials (i.e. the experimental programme) and its installation on board a Type 23 frigate. Most of the prospective users and operators will have had no previous contact with the system, and those that have will have been presented with a rather basic overview. It is critical that users and operators are able to understand and use the TDS Version 1 Phase 3 as quickly as possible, both in terms of their ability to operate it, and, more importantly for this research programme, for them to understand what the TDS is attempting to provide, and thus be able to make constructive criticisms based on their experience. Therefore the main objectives of this project are:

- To produce comprehensive training material for prospective users and operators of the TDS Version 1 Phase 3 as is to be used in the forthcoming shore based and sea trials. (N.B. Different training will be required according to the different roles of the operators and users).

- To run training courses at ARE, and to ensure that students are trained as quickly as possible to a sufficient level of understanding of the TDS that they are able to intelligently report on the TDS and contribute to its development.

- To evaluate and improve the quality of the training material based on student reaction, and in the light of how training can be improved to resolve and anticipate user and operator problems recorded during the sea trials of the TDS.

Technical Work Involved

The work will start from the TDS Version 1 Phase 3 , and produce an initial set of training material. This material will use various media - from blackboard and overhead slide presentations to hands-on experience with the TDS. The training course will be developed in line with current naval training practices, and should aim to produce a statement which outlines the purposes of the training material, and gives guidance to bodies such as HMS Dryad on developing operator/user performance standards for use of the TDS (Holman 1988).

General instruction in the ideas behind KBS will have to be given before the TDS as a specific example can be presented. It is unlikely that the first version of the material will be complete or ideal in format, nor will it necessarily be pertinent as the TDS is improved throughout the lifecycle of the project. The functionality of the TDS can be radically changed just by the introduction of a new rule, and training will never be able to give an exact education in the current TDS. The main objective will be to

communicate the underlying principles and modes of operation.

As each Version of the TDS is design-frozen, the implications for the training materials will be reported on. Revisions and alterations of the training material will be performed where possible in the lifetime of the research programme. Throughout the course of the research programme, the training material will also be evaluated in a classroom environment, and from observing the use of the TDS at sea. Evaluation will be based on feedback from students, and the the use of specific exercises designed to test whether students have gained the necessary understanding of the TDS.

The work will consist of four main activities:

a) Determining what the prospective users and operator will need from a training course, defining the level of ability required to conduct a training course, specification and production of a first version (I) of the training course(s). Running training courses.

b) Observing the teaching of the training course(s), interviewing students for expectations and opinions throughout the course. Observing users of the TDS in real operational environment following training.

c) Revisions of training course(s) material through iterations of (b) and from changes in the TDS (both in functional and HCI terms).

d) Recommendations for the incorporation of training into the TDS (i.e. embedded) via an intelligent tutoring system (see SP3.1.2.4)

Relation to Programme

The results of this project will contribute strongly to future designs of training courses in both Naval and TMD application areas, and there will be a very close relationship SP3.1.2.4 on Intelligent Training Systems.

Time and Effort

Human Computer Interaction	4 my
Total	4 man years over a 3 year period.

Inputs/Assumptions

The main initial input to this project will be the TDS Version 1, in its various phases up to Phase 3. As the lifetime of the research programme progresses then all changes to the TDS will change the form of course material (and it will be a problem for the training courses to always be completely up to date). SP4.1.1.2 will need to provide appropriate scenarios for instruction and exercise purposes. It is assumed that access to the training facilities under construction at ARE will be available. The concentration of effort will vary according to whether the recent ADQUAL applied for is granted - if it is then there will need to be increased effort in the short term to meet the expected demand for training (although it should be noted that effort will be at higher levels for the early part of the research programme anyway). The simulation facility currently under development by AXC5 will also produce a critical input in terms of producing

on-line, interactive training exercises.

Deliverables

- Course material (version I) for training user/operators on the TDS Version 1. Material will be in the form of teacher aids and guidelines, material for students in terms of basic information and computer based exercises on the TDS Version 1 Phase 3.
- Guidelines for operator /user performance standards which training needs to ensure are met.
- Hardware and Software for computer based components of the training course - simulations and exercises.
- Results and analysis of observers performing TDS based exercises during and after completion of training. Recommendations for improvements in training course.
- Incremental revisions (3 at most) of training course material as revised versions of the TDS are produced throughout the lifetime of the research programme.

Resources

Hardware: Workstation for designing computer based training aids £25k

Recording material for observing users of the system £20k

Hardware for user training, 5 Sigimex terminals with access to the appropriate Version of the TDS (under construction).

Other : Access to students for evaluation of training methods and material.

SP 2.1.1.1 Investigate Database/Knowledge Base interfacing techniques

Description

This experiment is concerned with establishing the most efficient techniques for coupling conventional databases and KBS.

Objective

- To investigate the ease of implementation and performance of techniques for interfacing a knowledge base with a geographical and encyclopædic database as the testbed.
- To recommend a route for the integration of databases within the TDS system, version 4.

Technical Work Involved

The TDS will be required to interface to a number of databases for access to static data when in operational use. The speed of access to that data could place a limit on the performance of the system as a whole. In the longer term, this may be overcome by the use of closely coupled database / knowledge bases, but in the short - medium term the most pragmatic approach involves treating the database and KBS components as discrete, loosely coupled entities.

This work will involve the creation of a model of the performance constraints imposed by different coupling techniques. This model will focus on the balance between data being held in primary and secondary memory. For a variety of application requirements the extent to which optimisation techniques are generalisable will be assessed. This assessment will necessitate experimentation with the techniques using the TDS Version 1 as a test-bed, and also the construction of tests for what are identified as the most critical areas of database/knowledge base interaction. From the model a set of alternative implementation routes will be defined and criteria for selection derived. Consideration of the distributed nature of the TDS requirement will be given.

The work will require the following activities :

(a) Investigation of TDS Version 1 rulebases to identify their requirements for database access. This includes both static inspection and dynamic logging of potential database I/O requests.

(b) Construction of a model of performance constraints for the TDS, treating the KBS and the distributed database as discrete components. The model must balance the extent to which tuning the coupling for specific needs may have a negative impact on its performance for other sets of requirements.

(c) Identification of the full range of different coupling techniques and the derivation of a set of tests that will demonstrate their effectiveness. Stress must be placed on the extent to which techniques of optimisation for the different architectural solutions can be generalised for different parts of the system : it is possible that using one form of optimised buffering may improve performance

in one part of the application, but make it worse in another part. A selected technique will be implemented on a trial basis (item (d)).

(d) Selection of a suitable database of information (such as the geographic or emitter information) to be used as the basis for the tests. A coupling technique will be implemented in trial form using one of these databases in order to offer proof of concept of the differing techniques identified in (c).

(e) Assessment of the different techniques and recommendation of a given route to interfacing, with a clear definition of its performance limitations and their impact on implementation

Relationship to programme

The coupling of the database and the knowledge base is a performance critical area of any overall system plan that treats these as discrete components. This work therefore makes a contribution to both TMD and the TDS. Timescales dictate that the methods developed could only be incorporated into Version 3 or 4 of the TDS.

Time and Effort

2 man years over 1 year.

Inputs / Assumptions

This work takes as its starting point the existence of the TDS Version 1 KBS component and a database of geographic and encyclopædic information. It is assumed that the application will involve a distributed database.

Deliverables

- a model of performance constraints with respect to the requirements of the TDS Version 1 application, bearing in mind its distributed nature
- a set of alternative strategies for the coupling of the database and KBS components
- an assessment of the extent to which the strategies identified can be actually applied to the TDS and recommendations on best choice

Resources

Access to the TDS Version 1 hardware/software and an installed database of geographic or emitter information, so that database interaction requirements can be assessed. This includes a need to instrument a running version of the TDS for dynamic assessment.

Access to a commercial database package will be required for experimentation purposes. This may need to be purchased by the project (cost approx £25k) depending on contractor facilities.

A workstation is assumed to be available to the contractor to perform any experimentation.

SP 2.1.1.2 Derive KBS performance and competence metrics for the TDS evaluation programme.

Description

This project is concerned with the definition and assessment of performance and competence metrics for the evaluation of KBS, and their subsequent application to the evaluation of the TDS Version 1.

Objective

This objectives of this project are to :

- Identify the KBS metrics requirements for evaluating as a non-interactive data fusion system TDS Version 1.
- Define KBS metrics which can be used to evaluate TDS Version 1.
- Evaluate the KBS component of TDS Version 1.
- Recommend KBS metrics for evaluating future KBS-based C^2 systems

Technical Work Involved

The TDS is soon to undergo a process of evaluation. The evaluation process has been subdivided into a set of seven objectives (Miles, J.A.H., ARE TDP/1.1/1). These include measurements of the performance of the TDS 'machine' (without manual assistance), and an assessment of its performance as an interactive data fusion system. This latter evaluation will be extended to include an assessment of the potential interactions between the TDS and the operator and command subsystems within which it would operate.

In order for that evaluation to be as effective as possible a set of meaningful metrics is required. These will need to encompass many aspects of system behaviour, including performance, competence and user interaction. This project will investigate the requirements of the trials programme and derive an appropriate set of performance and competence metrics for the evaluation of the TDS as a non-interactive data fusion system. It will then apply them to the evaluation of the TDS Version 1. The evaluation of the TDS as an interactive system is addressed in projects SP2.1.1.3, SP2.1.1.6 and SP2.1.1.7.

The major technical activities to be carried out are:

1 To analyse TDS Version 1 for metrics requirements. This will involve a definition of the parameters of the required performance envelope of the TDS, ie how can the inputs and outputs of the system be characterised (objects, processes, events, sensor characteristics, sources and nature of non-sensor information etc).

2 Generate appropriate metrics to assess TDS Version 1 as defined in (1) but at least addressing:

- performance
- robustness
- responsiveness
- systems overheads

The approach which is advocated is to derive as many of the metrics as possible by a statistical analysis of the behaviour of system modules. Finer grain analysis, of the behaviour of individual rules within modules etc., would be carried out only as required. This will involve the following tasks :

2.1 Analyse of the structure of the TDS and identify functional modules.

2.2 Define interfaces between modules.

2.3 Generate experimental scenarios with systematic variations in parameter values.

2.4 Derive appropriate statistical metrics to describe the processing tasks of the individual modules on the experimental scenarios.

2.5 Assess the need for on-line monitoring of modular function, eg rule firings, hypothesis tracing etc.

2.6 Develop and apply monitoring tools and, if required, prepare a modified version of the TDS Data Fusion module incorporating monitoring software.

3 Apply the metrics to a laboratory version of the TDS Data Fusion module Version 1, to generate an evaluation of the KBS component.

4 Analyse the trial data to assess the effectiveness of the metrics.

5 Generate recommendations on metrics for the evaluation of knowledge based C^2 systems.

Relationship to Programme

This project combines with projects SP2.1.1.3, SP2.1.1.6 and SP2.1.1.7 to provide a set of tools and techniques for evaluation of the KBS component of TDS Version 1 and will thus provide qualitative input to many of those projects in the enhanced-TDS and TMD activities.

Time and Effort

2 man-years over 2 years

Inputs and Assumptions

This project assumes the availability of results from the IED Gateway project which is carrying out research into metrics for KBS evaluation. Gateway will provide the basic set of KBS metrics which will be applied to TDS Version 1. It also assumes access to evaluation trials data.

Deliverables

Deliverables from the project will be:

- Analysis of the metrics requirements of TDS Version 1.
- Definition of KBS metrics necessary to satisfy the requirements identified in (2).
- Results of the application of the metrics to TDS Version 1.
- Recommendation of appropriate metrics for evaluating future KBS-based C^2 systems.

Resources

The hardware and software resources required for this project would probably be supplied by the TDP. However, it may also be necessary to have access to a workstation, plus appropriate statistical analysis software for the development and refinement of test metrics and statistical analysis tools.

Hardware:	AI Workstation	£25k
Software:	Stats. analysis	£5k
Total:		£30k

The following skills and experience are central to the success of this project :

- staff with practical experience in the derivation and use of KBS performance metrics, including statistical analysis software;
- experience at implementing different software solutions to specific KBS problems;
- experience of assessing highly interactive systems in a commercial or other non-academic environment;
- software engineering capacity (especially metrics) and an understanding of advanced techniques.

SP 2.1.1.3 Evaluation of the Impact of the TDS on the Operating Environment

Description

This project will investigate the impact of the TDS on the overall command and control system.

Although SP2.1.1.2 will evaluate the performance and competence of TDS Version 1 from a KBS perspective there are still a number of other evaluation activities which need to be carried out in order to fully assess the success of TDS Version 1 as a component of an overall command and control system. This project aims to satisfy some of those requirements related to the impact of the TDS on the operating environment.

Objective

This project addresses ARE objective EXPRO 6, and in particular the following aspects :

- Task, Job and Organisational effects.
- Effect on operator attitudes.
- Effect on workload of operations room personnel.

This project will also generate recommendations for assessing the impact of the TDS on manning levels and training requirements.

Technical Work Involved

In order to guide the future developments within the TDS programme it is necessary to evaluate a number of aspects of the impact of TDS Version 1 upon its operating environment. This research will investigate the impact of TDS Version 1 upon the overall C^2 system especially the Task, Job and Organisational impact and the effect on operator attitudes and workload.

The major technical activities will be carried out in the course of the evaluation trials, and will be :

1. Partition the information processing tasks of the operations room to identify the functional tasks related to data fusion. Identify, characterise and quantify the nature and flow of information between individuals within the command structure

2. Set up an experimental operations structure, and define command and information flow protocols.

3. Define a series of scenario exercises in which the TDS is used in full interactive mode.

4. Monitor the performance of individuals, and the interactions between operations

room personnel during the trials.

5 Analyse the data from the trials, to evaluate the impact of TDS Version 1 upon the overall C^2 system, in particular the Task, Job and Organisational impact.

Relationship to Programme

In order to guide the future development of the TDS it is important to fully evaluate the existing system. This project forms a part of the overall TDS evaluation process in particular complementing the KBS performance evaluation which will be carried out by SP2.1.1.2. The project will utilise the methods and tools resulting from SP2.1.1.4. The results of this project will provide input into SP2.1.1.9 on the evaluation of the TDS as a data fusion system.

Time and Effort

Research Team effort : 1.5 man-years over 1 year

There will be an additional requirement for effort from the AOT3 Exercise Analysis Team from the Central Support project SP4.1.1.7.

Inputs/Assumptions

This project assumes the availability of TDS Version 1 for evaluation purposes and the collection and initial analysis of data by the AOT3 Exercise Analysis Team.

Deliverables

Deliverables from the project will be:

- Results of evaluation of effect of TDS Version 1 on the overall C^2 system, in particular the Task, Job and Organisational impact.
- Recommendations on the potential effects of the TDS on operator workloads and manning levels.

Resources

Hardware: No specific requirements
Software: No specific requirements

The following skills and experience are central to the success of this project :

- staff with specific experience of monitoring the organisational and operational impact of software systems to time-critical and mission-critical decision making;
- sufficient applications experience to provide realistic scenario data;
- staff with C^2 experience and operational systems development experience.

SP 2.1.1.4 Develop Design Methods and Tools for Task Analysis

Description

This project will develop design methods and tools for task analysis, goal analysis and allocation of function for specifying the user requirement from the TDS. The user requirement will be considered in terms of operational, organisational, and training issues.

Objectives

The objective of this project is:

- To identify methods and tools for task analysis of C^2 applications.
- To analyse the SAP-1 using these techniques and to produce prototype implementations of some of the recommendations.

Technical Work Involved

The TDS Version 1 has an HCI which was designed using a series of interviews with a range of prospective users and incorporated much of what the TDS developers felt were the HCI requirements. The resulting HCI exists primarily for the Data Fusion Module of the TDS. The situation for the further developments of the TDS, including the Situation Assessment Prototype (SAP) presents a different, but no less complex and demanding picture in terms of the requirements placed upon the HCI.

By building an appropriate set of models which show the respective roles of human and computer, progress towards correct and efficient system functionality can be achieved. A number of models exist for performing task analysis, and their applicability in the C^2 domain needs to be determined properly. The project will aim to produce a set of models and tools for task analysis in the C^2 environment together with examples of their implementation and evaluation for a part of the TDS.

The project will focus on developing a three stage approach to improving the HCI component for the TDS. First a particular function in the C^2 hierarchy will be chosen (likely to be Situation Assessment). This will then explored to determine as accurately as possible its expected role in the overall C^2 task, followed by a range of recommendations for implementation further developments of the TDS to enable it to achieve these aims. These recommendations will be implemented in software where possible and then evaluated via laboratory (and possibly ship-based) experimentation.

The work will consist of three main activities:

a) An evaluation of the applicability of existing techniques to the HCI for C^2 systems will be conducted, and those most suitable to further developments of the TDS will be recommended.

b) The design of the SAP-1 will be analysed using those techniques selected under (a), relevant system documentation will be examined, together with

interviews of appropriate personnel and observation of current system operations and operation of the TDS. This will enable the construction of a model of the putative task structure for TDS operation. Recommendations for the design specification of certain aspects of the HCI will be made, subject to the capabilities and limitations of task analysis methods The application of goal elicitation techniques to HCI will also be investigated.

c) Aspects of the HCI specifications made under (b) will be implemented in software, primarily as extensions to TDS version 1. The success of these implementations will then be tested using a series of experiments. These results will be used to then further improve the HCI via an iterative process.

Relation to Programme

This project is closely related to the program of work being conducted to enhance the TDS. If successful it will lead to increased operational capability for any part of the TDS which can be successfully subjected to a similar set of analysis procedures.

Time and Effort

Human Computer Interaction 2 my

Total 2 man years over a 1 year period.

Inputs/Assumptions

The major input to this project will be access to TDS Version 1 Phase 3 for analysis and SAP-1 for experimentation. It is assumed that reasonable access to experienced C^2 operators and users will be possible during the initial (and any subsequent) interview phases. A version of the TDS which could be customised and dedicated to HCI experimentation would also aid this project significantly.

Deliverables

- Analysis of the applicability of existing HCI methods for task analysis, goal analysis, allocation of function, and goal elicitation when applied to the C^2 problem.

- Analysis of the results obtained from applying the techniques selected to a particular module of the TDS (SAP). Recommendations for design of HCI arising from this study.

- Software implementing subset of HCI design recommendations for SAP-1.

- Analysis of the results obtained from experiments conducted using the software developed in the previous deliverable. Recommendations for changes in the implementation, together with suggestions for a second pass at the interview phase.

Resources

Hardware:	VAXstation	£25k
Software:	Ada Compiler	£7k
Total:		£32k

In addition it is assumed that access can be gained to appropriate TDS experts.

SP 2.1.1.5 Optimisation of HCI Design for Tactical Picture Displays

Description

This project will continue the work done to date at ARE on the development of tactical picture displays. It will use and extend the software already in existence to conduct experiments aimed at producing an optimal set of symbols and picture display parameters for the data fusion and situation assessment modules of the TDS.

Objectives

The way information is presented on a visual display has an important effect on a user's ability to perform his tasks. The problem is aggravated in the C^2 task, as there is nearly always an 'overload' of information which can be presented. Experience to date with the design of the user interface of the TDS has shown that the design of the tactical picture display is not yet optimal (Byrne89). Although there is a large body of HCI knowledge on the display of information in the form of guidelines and standards, little, if any, addresses in a formal manner how display information might be quantified for a particular problem. The objectives of this project are:

- To set up an environment in which human factors experiments based on the tactical picture display component of the TDS Version 1 and the Situation Assessment Prototype (SAP) can be conducted.
- To assess and quantify the quality of the existing tactical picture display for the data fusion and situation assessment modules of the TDS through a set of observer experiments.
- To produce a set of criteria for evaluating the quality of a particular tactical picture display.
- To modify the existing tactical picture display software based on the results of the observer experiments.

Technical Work Involved

Work to date on the TDS developed a symbology which was felt to be judgementally correct, but which has not been fully evaluated under experimental conditions. While there are a large number of studies into the design of symbols for C^2 systems, and NATO standards exist (STANAG 2019) these are continually under review, and rarely can be applied except under a rigid set of *a priori* constraints. Tactical displays tend to be as unique in their design as are the systems which produce the information they have to display. Previous work on the TDS identified the need for a more rigourous approach to the design of symbology , and it is not possible at this stage to specify a symbology other than the condition that the ability to change or have more than one symbol set is required. Therefore, this project will continue the work done to date aspects of information presentation on displays, the design of symbology, graphics and interaction techniques. The impact of the tactical picture display on the command function will be investigated, including the relationship of the tactical picture display to other work on adaptive interfaces (SP2.14.1), the design of explanation facilities, (SP2.1.3.4) and the aspects of team structure and team performance which affect the display interface.

The work will consist of four main activities:

a) Developing an HCI prototyping testbed for the investigation of alternative representations within tactical picture displays. This will utilise the existing ARE hardware (Sigimex) and the software developed to date for symbol, background, text, graphical primitives and overall tactical picture display creation.

b) Using (a) to run a series of human factors experiments with prospective operators for investigating the optimal transfer of information between a user and tactical display systems of the data fusion and situation assessment modules of the TDS. A set of test scenarios will be specified and generated for these experiments. Attention will be focussed on different designs and uses of symbology and other graphical representations.

c) Modifing the existing tactical picture display software based on the results of the experiments.

d) Based on the results of other projects in the research programme (see SP2.1.3.4, SP2.1.4.1), examining the effects of incorporating new ways of representing explanations and uncertain information.

Relation to Programme

This project will have a close relationship with other projects specifically based around the display aspects of HCI such as SP3.1.2.4 on appropriate techniques for explanation in situation assessment systems, and SP2.1.4.1 on adaptive interfaces for C^2 systems. The prototype projects for the TMD based applied research: SP2.2.3.1 on adaptive preferential defence, SP2.2.3.2 on sensor management, and SP2.2.3.3 on the intention prediction of intelligently moving objects all have HCI components which will use the results of this project.

Time and Effort

Human Computer Interaction	2.5 my
Total	2.5 man years over a 2 year period.

Inputs/Assumptions

The main inputs to this project will be the TDS Version 1 and the Situation Assessment Prototype (SAP). Specified scenarios will need to be generated as part of SP4.1.1.2. The project will not aim to change the current hardware facilities used for the displays (i.e. Sigimex displays), rather it will seek to utilise that hardware in an optimal manner. Results from other projects will generally feed into this work, e.g faster response times, new forms of knowledge representations etc.

Deliverables

- Software for generating a range of display formats and graphical primitives for producing a range of symbology sets. Provision of font sizes and types for experimentation with textually presented information.

- Hardware to present information as it would occur in a real world scenario (N.B. this would not recreate a full control room environment, merely the display environment for a single TDS operator).

- Specification of a set of scenarios for conducting a series of observer experiments based on the TDS Version 1 and the SAP.

- Software environment for running observer experiments using alternative symbologies, backgrounds, and graphical representations.

- Analysis of observer experiments. Criteria for evaluating the tactical picture displays.

- Modified software for the generation of tactical picture display for inclusion in future versions of the TDS and Situation Assessment Prototypes.

- Recommendations for further improvements to be made to the overall tactical picture display based on the results of SP2.1.3.4 and SP2.1.4.1.

Resources

Hardware :	Workstation	£25k
	Sigimex Display and Connections to Workstation	£20k
Software :	Ada compiler	£7k
Total :		£52k

SP 2.1.1.6 Evaluation of the effects of Operator Interaction with the TDS

Description

This project will generate a set of techniques to analyse and evaluate the level and effect of operator interaction with the TDS. It will assess the impact of the interaction on overall performance of the TDS via a series of human factors experiments.

Objectives

As part of the declared strategy of the TDS experimental evaluation programme, ARE have declared the following objective:

- To analyse the human components effects on performance of the TDS system as a whole (issues include whether the tactical picture can be improved by user modification, and the identification of the manual interactions made in assisting TDS performance), and to identify potential knowledge based enhancements and necessarily human contributions.

In order to meet this objective, this project will aim to:

- Run a series of human factors experiments using previously specified scenarios designed to test the range of interaction between the operator and the TDS Version 1 Phase 3. These will explore the effects of such interactions upon data fusion performance and identify the nature of the human contribution so that the necessary roles of human (Molyneux 1990a) and knowledge base components in the data fusion process can be amended and refined where appropriate.

Technical Work Involved

As part of the task decomposition between man and machine, the level and form of interaction between the operator and the TDS Version 1 Phase 3 has already been specified (Molyneux 1990a, Miles 1989). For example, PWOs will be allowed to cause decorrelation or correlation, but not delete tracks or actually modify the rule base. The strong KBS component of the TDS means that there is a range of potential situations which could occur in system operation which must be anticipated and analysed before full operational status can be assumed.

Not all scenarios or aspects of KBS behaviour can be predicted a priori, but the following will be addressed: the effect on user confidence of updating the knowledge base to produce different results for previously seen scenarios, the degree to which the KBS can ask the operator for information to support its inference processes, the extent to which operators can expect to modify the knowledge bases themselves, and the dynamic setting of system parameters to increase operational speed, or produce more reliable outputs.

Aspects of the KBS involvement in the TDS will dramatically change according to the current state of the world, for example in a full battle situation, the operator is likely to take an increased role in the decision making process, and is also likely to request for more concise explanations from the system. Some of these interactions are legal, and others are currently not permitted.This project will explore the nature, content and effect of all forms of operator interaction (both actual and desired) with the TDS

Version 1 Phase 3. It will run a series of experiments aimed at identifying those forms of interaction which take place consistently across a number of operators, as well as discovering which forms of interaction have not been adequately catered for (it should be noted that the latter result will also have an input to the level of user confidence in and acceptance of the TDS).

The work will consist of four main activities:

a) Providing software for monitoring all forms of manual interaction between the operator and the TDS. This should be capable of recording time and form of interaction (i.e. which key was pressed and which track/object was affected, or what level of explanation was requested).

b) The specification and design of a set of scenarios aimed at examining the effects of operator interaction on the TDS. Scenarios will be designed with a view to the following: testing whether different levels of allowed operator interaction can improve the tactical picture produced by the the TDS Version 1 Phase 3; to see if there is any consistency across a number of operators in the nature of their interactions for certain scenarios; to examine the effect on operator interaction of extended periods of use of the TDS; to explore the level of interaction under different higher level command directives; to determine the level of operator interaction necessary to maintain interest levels.

c) The running of a set of observer experiments using the scenarios defined and a range of different prospective operators of the TDS. The following will be considered : recording of all the interactions made and the resulting tactical pictures for each scenario; playback of scenarios together with interactions to facilitate operator interviews in order to determine why particular interactions were made; operator reactions to the level of interaction allowed; analysis of scenarios for multiple observers to determine consistent forms of interaction. These experiments will be initially run using the SDF at ARE, and the most effective will then be redesigned for running during sea trials.

d) The analysis of the results of (c) to assess the current HCI design for operator interaction. Criteria will use measures of the frequency of interaction, the reaction time before interactions, the reliability of interactions (both in terms of the actual form of the interaction , and in the effect of the interaction on the final tactical picture), and the subjective opinions of the observers used in the experiments (operators will be asked if they liked or needed the use of features such as explicit enter, feedback information, undo facilities etc.). Recommendations for improvements in the form of the operator interaction with the TDS and the knowledges base will be produced

e) Prototype implementation of the proposed recommendations, and rerunning of a subset of the experiments to observe any change in interactions between operator and the TDS, and the overall quality of tactical picture compilation.

Relation to Programme

This project would complement the work being done in SP2.1.1.3 on the evaluation of the impact of the TDS on the operating environment. Results will be used in SP2.1.1.7 on the validation and assessment of the man-machine interface of the TDS, and also in forming the design of the HCI for any of the stand alone prototypes being

developed under the TMD applied research stream such as SP2.2.3.1 on adaptive preferential defence, SP2.2.3.2 on sensor management, and SP2.2.3.3 on the intention prediction of intelligently moving objects. All have HCI components which will use the results of this project. If operators and users are eventually allowed to interact at the level of altering the knowledge and rule bases, then subjects such as KBS maintenance (SP2.1.3.1) will be related to this project .

Time and Effort

Human Computer Interaction	2 my
Total	2 man years over a 1 year period.

Inputs/Assumptions

SP2.1.1.2 will provide software for monitoring the functional and performance related behaviour of the TDS Version 1 Phase 3. It is likely that a greater degree of flexibility of scenario will be necessary than is currently available, therefore SP4.1.1.2 will also provide input to this project, and it is also assumed that the simulation facility currently under development by AXC5 will be completed to enable interactive scenarios of limited functionality to be run for observer experiments. Access to the SDF TDS Version 1 Phase 3 is required, and assumes the existence of recording equipment as well as access to operators for interviews and taped interaction sessions. Some access to the sea-based version of the TDS will also be required.

Deliverables

- Specification of test scenarios and experimental conditions for the experimental programme to evaluate the current specification of operator interaction with the TDS.
- Criteria for evaluating the effect of operator interaction on the overall behaviour of the TDS.
- Results and analysis of a set of observer experiments conducted on the SDF at ARE to test the nature, content and effect of user interaction with the TDS Version 1 Phase 3.
- Further running and analysis of selected experiments to be conducted on the sea based version of the TDS.
- Recommendations for changes in the HCI component of the TDS (and knowledge bases where appropriate).
- Results of experiments run using revised HCI incorporating new user model.

Resources

Hardware:	Equipment for recording experiments on sea based TDS £10k
Total :	£10k

SP 2.1.1.7 Validation of the TDS HCI

Description

This project will assess and validate the TDS HCI and identify the HCI facilities required to support a KBS Data Fusion System.

Objectives

As part of the declared strategy of the TDS experimental evaluation programme, ARE have declared the following objectives:

- The assessment of the HCI at three levels :

  (1) Presentation (sensory-motor) which will include operators' and users' views on colour, shapes, input devices, window content and format of information.

  (2) Information level which refers to the way in which the operators and users use windows menus etc.

  (3) Understanding level which refers to the extent to which the operator or user has an overall appreciation of and understands the system.

- The usability issue should be addressed, i.e. how easy do the operators find the system to use.

- An assessment of features which are due to the KBS nature of the TDS will also be required, e.g. explanation facilities.

This project is specifically aimed at meeting these objectives, together with an assessment of the whole process of HCI specification, design and implementation, the results of which can be used to specify future HCI requirements for the procurement of C^2 systems.

Technical Work Involved

The development of the HCI for the TDS has been a four stage process. First the system tasks were defined. This led to the definition of an HCI requirement specification (Molyneux 1990b), which in turn resulted in the design of the HCI component of the TDS and its associated implementation. The work will aim to evaluate the success with which this process has been conducted. It will verify that the implementation of the design specification has been correct. It will also try to determine whether the HCI requirement specification was correct and complete. Finally it will examine whether the proposed system tasks are those which are actually encountered in the real-world scenarios encountered during sea trials of the TDS.

The work would consist of three main activities:

a) Development of an appropriate set of criteria, metrics, and methods of measurement for assessing the HCI component of the TDS Version 1 Phase 3. Specification of a set of appropriate scenarios for running observer

experiments designed to assess various aspects of the HCI. The criteria will be based on the ability of operators and users to perform certain tasks, together with questionnaires and interviews to gather user and operator's subjective response to the HCI. Tasks will be designed with an emphasis on the assessment of the HCI as a separate component of the TDS, and on verifying the user requirement for the HCI. In the case of explanation facilities a scenario will be created whereby the explanation facility should be invoked by the operator. In the case of a final tactical picture display, how quickly and accurately the crucial information been presented will be assessed.

b) Running a set of repeatable experiments (as specified under (a)) with a number of observers to obtain a consensus of opinion. Observers will also be given the chance to "configure" the HCI as they would wish, and then asked to explain their decision making process. Assuming that the implementation of the design has already been verified, then these experiments will contribute towards verifying whether the HCI requirement has been included in the design. It should also enable additions and modifications to the original user requirement to be elicited and included where possible (together with the any associated changes in the HCI design and implementation).

c) Although the experiments conducted under (b) will be as thorough as possible, it will be impossible to recreate the complete task and operational environment that will exist at sea. Any parts of the HCI which still remain ambiguous in terms of an assessment of their quality at the end of (b) should be considered for a set of focussed observer experiments to be conducted as part of the sea trials of the TDS. The sea trials will also present the best opportunity of trying to validate the originally specified system tasks. Recordings of extended "free play" use of the TDS will be made and analysed to see whether the tasks conducted correspond to those used to formulate the initial HCI requirements specification.

Relation to Programme

The results of this project will be important for other projects involving the design and possible evaluation of an HCI component, for example SP2.1.2.4 on HCI for Situation Assessment and Resource Allocation, and SP2.2.3.2 on Sensor Management. This project will have a close relationship with the other projects aimed at evaluating and assessing the TDS, notably SP2.1.1.6 on the Effect of Operator Interaction with the TDS, and to a lesser extent SP2.1.1.3 on the Evaluation of the impact of the TDS on the Operating Environment.

Time and Effort

Human Computer Interaction 3 my

Total : 3 man years over a 2 year period.

Inputs/Assumptions

The main inputs to this project will be the TDS Version 1 Phase 3 as produced in the development programme, and some of the software and evaluation metrics produced under SP2.1.1.2 'Deriving KBS Performance and Competence metrics for the TDS Evaluation Programme'. It is assumed that the HCI component of this version of the

TDS will be of high enough quality to enable the experiments outlined above to be conducted. It also assumes that the simulation facility currently under development by AXC5 will be completed to enable interactive scenarios to be run for observer experiments.

Deliverables

- Analysis and evaluation of each of the major constituents (i.e. display format, representation of information, input devices etc.) of the HCI component of the TDS Version 1 Phase 3.
- Verification of the HCI design against the HCI requirement specification.
- Modifications to the HCI requirement specification.
- Recommendations for changes in the HCI component of the TDS Version 1 Phase 3.
- Implementations (where possible) of recommended changes to TDS Version 1 Phase 3
- Validation of system tasks as used for basis of HCI requirement specification.
- Identification of validated HCI requirements for a knowledge based data fusion system,

Resources

Access to the SDF version of the TDS Version 1 Phase 3 for conducting the initial assessment. Access to the sea based TDS for further observer experiments to validate the initial choice of system tasks.

The following skills and experience are central to the success of this project :

- staff with HCI analysis experience of operational systems;
- non-academic experience of HCI in a military task domain, providing a basis for rapid assimilation of the TDS task structure;
- broadly-based HCI skills to ensure all aspects of the system can be adequately covered;
- staff with KBS experience in the area of C^2 and Data Fusion.

SP 2.1.1.8 To evaluate the TDS as a data fusion system

Description

This project will evaluate the TDS as an interactive data fusion system, performing in an operational environment. It isolates the performance of the TDS from considerations of peripheral issues such as sensor capabilities, and includes an assessment of the man-machine complex in comparison with more conventional systems for tactical picture compilation.

Objective

This project addresses ARE EXPRO 1, the components of which are :

- To assess the quality of tactical picture which can be generated by the TDS, working in conjunction with the operator in an operational context.
- To provide an objective measure of the performance and competence of the TDS which can be assessed independently of peripheral factors such as sensor performance.
- To provide an initial indication of the characteristics and capabilities of the TDS relative to more conventional systems.

Technical Work Involved

1 Apply the system metrics derived from SP2.1.1.2 to a series of laboratory scenario exercises in which the TDS is used interactively, and hence derive a set of operational metrics, which take into account the effects of user interaction.

2 Define a series of parallel exercises, designed to compare the operation of the TDS with that of a current generation C^2 system on a similar vessel, using similar sensors on the same scenario.

3 Collect the data, and analyse the results of the comparative trial, using the metrics developed in SP2.1.1.2 and this project to separate the effects of differences in sensor and operator performance from those attributable to the TDS.

Relationship to Programme

This project draws on the results of the KBS Metrics project, SP2.1.1.2, and integrates them into a comprehensive assessment of the TDS as an operational data fusion system. It also draws on the results of SP2.1.1.3 for the partitioning of tasks and roles within the operations room environment.

Time and Effort

Research team effort : 2 man-years over 1 year.

There is an additional requirement for up to 2 man-years of effort from the AOT3 Exercise Analysis Team from the Central Support project SP4.1.1.7.

Inputs and Assumptions

There are two significant inputs to this project :

- The metrics generated in project SP2.1.1.2
- The collection and initial analysis of data by AOT3 Exercise Analysis Team.

Deliverables

The project will generate the following deliverables :

- An extended set of performance and competence metrics, which can be used to assess the performance of the TDS as an interactive data fusion system.
- The results of an evaluation trial to compare the performance of the TDS with a conventional C^2 system.

Resources

This project will not require specialised hardware or software, other than that provided by the TDS. However, there may be a need for some software support for statistical analysis.

Statistical Analysis software £5K

The following skills and experience are central to the success of this project :

- experience of the implementation and assessment of different Naval systems in a sea-going environment
- recognised excellence in the definition and application of KBS metrics

SP 2.1.2.1 Enhanced Situation Assessment Prototype

Description

This project is concerned with the extension of the Situation Assessment prototype (currently being procured) to enable its more direct use in an operational context and to rationalise the representation schemes as a basis for further work in resource allocation and planning.

Objectives

The project aims to develop a new Situation Assessment prototype addressing:

1. The generation and manipulation of multiple uncertain possible interpretations of the tactical picture.

2. Robust portable representation primitives for Situation Assessment, Resource Allocation and Planning.

3. Storage mechanisms for real-time manipulation of the above.

Technical Work Involved

Overview

A Situation Assessment system for the operational environment must integrate with and support the existing naval operational methods and structures. In operational command and control systems, users directly acknowledge the uncertainty that exists in their interpretation of the tactical picture. They will maintain at least two projections of the current situation - one assuming the worst case (given blue force intentions) and one the most likely case (given best current knowledge). Part of this project therefore addresses these issues, extending the prototype to incorporate appropriate mechanisms. This has implications for knowledge representation and manipulation, the storage of such data and the interfaces to potential operators.

As well as extending the capability of the Situation Assessment prototype in this way, this project is intended to revisit that prototype to refine its representations, particularly to support the upper levels of the C^2 function hierarchy, eg. resource allocation and planning. There are two reasons for wanting to improve the representation to be used at the Situation Assessment level:

1. Designing robust reasoning systems, that is ones whose performance will degrade gradually rather than acutely, requires specific representations.

2. The choice of good primitives gives durability in the sense that they are valid for all uses of the same information by different components of the overall system. It is important for representations to be valid for several uses if repeated descriptions of the same information are to be avoided within the system. This is not only wasteful but introduces maintenance difficulties.

Temporal, Spatial and Modal features of the domain would all benefit from explicit treatment. These representations will be incorporated into the new reasoning process

of the SA system.

Research Components

1. Knowledge Representation and Manipulation

The knowledge representation aspects of the project are required to address the implications of treating uncertainty through maintaining multiple world pictures or other methods. The existing SAP will need to be evaluated for any performance shortcomings and from the point of view of including more explicit representations.

New representations for temporal, modal and spatial domain features and a prototype system will need to be constructed. The prototype is again expected to be compatible with data fusion level output representations of the contemporary TDS, though it will not be integrated with it.

2. Database / Knowledge Base Interaction

In the Situation Assessment process extensive use is expected to be made of database information on geographic data, possible plans, emitter characteristics, etc. As new representations are being created (in component 1) these will require appropriate and efficient storage mechanisms to be obtained or developed.

3. Human Computer Interaction

The HCI for the Enhanced SAP should address the issue of representing uncertainty and supporting the generation of multiple predictions of potential enemy actions.

Relation to Programme

This project is a major opportunity for revisiting representation methods in use within the complete range of Command and Control system components. As a result this work should partly be viewed as enabling for projects such as the Enhanced Resource Allocation prototype (SP2.1.2.2). SP2.1.3.2 on the other hand will be of great importance to this project as it is concerned with elicitation of the kind of constructs we wish to represent here.

The representations to be developed should be largely applicable to TMD experiments as well (with the proviso that three-dimensional spatial reasoning will be more of a requirement for TMD), thus work in the TMD stream on threat assessment, weapon management and adaptive defence will benefit.

On the HCI front projects SP2.1.3.4 "Techniques for Explanation in Situation Assessment Systems" and SP2.1.1.6 "Operator Interaction with C^2 Systems" are clearly relevant and could either feed in to or benefit from this project.

The portability of scenario data from SAP-1 experiments is expected to be addressed in SP4.1.1.2 "Scenario Generation and Data".

Time and Effort

Knowledge Representation and Manipulation	3 my
Database / Knowledge Base Interaction	2 my
Human Computer Interaction	2 my
Total	7 my over 2 years

Inputs / Assumptions

Interactions, or potential interactions, with other projects have been highlighted above. The project is largely independent of other efforts, though there is a clear need to be able to examine and evaluate the original SAP when it is complete.

Access to naval expertise is required for the project. Two to four man weeks of an appropriate officer's time should be made available either by the contractor or through naval channels.

Deliverables

- a prototype (SAP-2)
- a candidate set of representations to feed into the resource allocation system prototyping and perhaps the data fusion layer.
- a situation assessment knowledge base.

Resources

On the assumption that scenarios for SAP-1 will contain some interpretation ambiguity, no further scenario data need be necessary. It is also assumed that test scenarios for SAP-1 will be intended to show weaknesses in its approach for which SAP-2 will be able to compensate.

Hardware:	AI Workstation	£25k
Software:	AI Toolkit	£15k
Total:		£40k

These hardware and software resources should already be available at any appropriate contractor's site. It is not expected that ARE will need to purchase them; this work can be done at the contractor's site.

The following skills and experience are central to the success of this project :

- experience at applying different reasoning techniques and representations to time-critical areas;
- experience of static and dynamic database integration for real-time systems;

- exposure and use of a range of novel database structures (eg object-oriented databases) in real-world application areas;

- staff with situation assessment experience in the context of Naval C^2 are highly desirable;

- derivation and use of models and software to represent multiple worlds and potential actions (for plan representation and modification).

SP 2.1.2.2 Enhanced Resource Allocation Prototype

Description

This project is concerned with enhancements to the Resource Allocation Prototypes to support their continued development as decision support tools and the refinement and rationalisation of their internal workings.

Objectives

The aim of the project is the production of a demonstrator system appropriate for experimental use by warfare officers. The objectives are therefore:

- to integrate representation systems developed for SAP-2 into resource allocation prototypes;
- to re-evaluate the performance of Resource Allocation (RA) prototypes and modify their architecture or update their knowledge bases as appropriate;
- to design and implement an integrated decision support system based around reactive and background RA processes co-ordinated through the main battle plan.

Since the intention is to get closer to an operational capability than the previous resource allocation prototypes, a further objective is:

- to develop a better understanding of the dissemination of plans within the command and control structure and their use by warfare officers.

Technical Work Involved

Overview

The purpose of developing resource allocation systems is to provide decision support to the various warfare officers. These officers will be directing aircraft, sensor and weapon systems toward the achievement of a tactical goal, co-ordinated by the plan that they will have been involved in generating with the Force Commander and other operations officers. Their tasks will be two-fold, one a reactive process in response to events and developing situations shown by the tactical picture, one a background process of resource management ("readiness maintenance"). Reactive allocation decisions have several constituents other than the situation; eg. the characteristics of a resource and its current value (the last round is worth more than the first), the implications of deployment (chaff may obscure weapon engagement arcs) and the value of the outcome (the effect of either taking an action or not taking the action).

The enhancements to RA prototypes that are proposed for this project fall into two categories, those that extend the functionality and those that improve the existing mechanisms. Defining the former category is difficult without a specification of the contents of RRASSL. The problems of force-level resource allocation will fall within the scope of this project. So will the co-ordination of resource allocations with reference to the overall task-force plan and objectives. Improvements to RAP and RRASSL are expected to take the form of incorporation of new representations developed during the SAP-2 project and other improvements or extensions to the knowledge bases. The integration of earlier RAP and RRASSL prototypes is also a goal.

Research Components

In the components identified below, Human Computer Interaction is noticeable by its absence. There is a reason for this. SANDERLING Project 3.1.1.2 "Co-Operative Planning Aids for Command and Control" addresses the issue of planning and resource allocation from the higher level and is particularly concerned with the man-machine interface needs for both functions. It is therefore anticipated that the appropriate research issues will be covered there, and that this project will draw upon some of that work in the development of the user interface for the demonstrator.

Components are:

1. Development of plan representations and their incorporation into analysis functions during evaluation of allocation alternatives. The plan is to represent the task force's overall tactical goals and plan, and will form part of the context for the selection of resource allocation actions.

2. Production of demonstrator using plan description as a means of integrating previous RA prototypes. This also incorporates the representation primitives developed during SP2.1.2.1 for "Enhanced Situation Assessment". This demonstrator will not be integrated with TDS or other prototypes, but should be compatible with SAP output types and formats.

3. Development of database techniques for storage of plan information, response scripts and dynamic data such as resource status. It is assumed that database mechanisms for storage of the temporal, spatial and modal data have already been developed in SP2.1.2.1; the new mechanisms must build on top of those for these new types of knowledge items.

Relation to Programme

The technical work is supported by earlier resource allocation prototyping, such as the FLYPAST system and the single-ship resource allocation prototype (RRASSL) that is in the process of being procured. It also draws on work that will be done on Knowledge Representation as part of the SAP-2 research (SP2.1.2.1). In that project representational primitives for spatial and temporal characteristics will be developed, along with modal representations for enemy intentions. The rationale behind their development is that they will form the basis for work such as RAP-2, indeed the usefulness of knowledge representation research will only be comprehended if they are used here.

The resource allocation being discussed here is a co-ordination function conducted with respect to a higher level plan. This plan, its generation and use in resource allocation are the subject of SP3.1.1.2 'Co-Operative Planning Aids for Command and Control'. As indicated above, some HCI aspects will also be addressed in SP3.1.1.2. SP2.1.2.4 will also be tackling HCI issues of relevance to the development of the new RAP.

Time and Effort

Knowledge Representation / Manipulation	4 My
Database / Knowledge Interaction	1 My
Total	5 My over 18 months

Inputs / Assumptions

The project will require input from previous prototyping work on Situation Assessment and Resource Allocation functions, since it will be attempting to refine some of that work, or apply its new knowledge representations to the RA problem. This will include the need to run those demonstrators on realistic and taxing scenarios.

The project would benefit enormously from the active involvement of warfare officers such as an ASW or AAW Co-ordinator, providing both knowledge and information on the operational context in which such a system would be expected to work. Two to four man-weeks of such effort needs to be included in the project to be provided either through ARE or by the contractor.

In describing the various research components that contribute to the development of a demonstrator, some assumptions are made as to the likely contents of the RRASSL programme (Reactive Resource Allocation at Single Ship Level). For example, it is assumed that the RRASSL system will be built to interface to SAP-1 and will therefore be driven from the *Threat Priority List* that it will produce. Furthermore, it is assumed that RRASSL will primarily be script-based, ie. it will perform resource allocation by matching some situation description against a set of stored scripts and instantiating the most appropriate one.

Deliverables

- An enhanced Resource Allocation demonstrator.
- Reports on any shortcomings of the approach discovered during the work and the steps required to operationalise the system.
- A resource allocation knowledge base.

Resources

Hardware:	AI Workstation	£25k
Software:	AI Toolkit	£15k

Total: £40k

These hardware and software resources should already be available at any appropriate contractor's site. It is not expected that ARE will need to purchase them; this work can be done at the contractor's site.

Scenarios proposed or generated for other resource allocation projects will be applicable here. A scenario involving both background and reactive resource management will be needed.

Access to results from previous work on resource allocation is needed, including the opportunity to evaluate the prototypes.

SP 2.1.2.3 Enhanced TDS Performance by Concurrent Processing

Description

This project will continue the work done to date at ARE on examining the potential for exploiting concurrent processing within the TDS Version 1 Phase 3.

Objectives

Speed of operation has been targetted as a critical factor in determining the TDS system's acceptance as a valid solution to the C^2 problem (Miles88). Recent advances in hardware, together with appropriate software programming environments, mean that concurrent processing is a much more readily accessible technology. The objectives of this project are:

- Continue the work on examining rule bases in specific knowledge sources for static and dynamic parallelism (Daniel88).
- Investigate the use of concurrent processing as part of any matching algorithms e.g. The RETE algorithm (Minraker89).
- Assess the potential for the use of fine and coarse grained parallel solutions and architectures for all aspects of the data fusion module.
- To run a series of experiments to show increases in the operational speed of the the TDS Version 1 through prototype implementations of the above techniques on a concurrent computing system.
- Ensure that the problems traditionally associated with the deployment of concurrent processing systems (deadlock, livelock, communications becoming overloaded) are accounted for in the control structure of any version of the TDS incorporating concurrent processing.
- To specify concurrent processing elements for future versions of the data fusion module of the TDS.

Technical Work Involved

The work will build a set of prototypes to show what performance improvements can be expected from a number of different uses of concurrent processing within the TDS Version 1 Phase 3. The ability to concurrently process information may result in increased speeds of performance, but these will only be of operational significance (i.e. at least one order of magnitude) if the underlying paradigm is designed to be implemented in this manner. It is difficult to take a system developed under an inherently sequential regime and improve its performance by simply 'adding' concurrent processing The project will therefore evaluate the effects that a more extensive implementation of concurrent processing would have on the global control architecture and paradigms proposed for the TDS. This would certainly have a bearing on the longer term application such as TMD. Areas which are identified as promising will then be investigated in more detail through a series of prototypes developed on a concurrent computing system (e.g. a Meiko system); the complete effects of concurrent processing cannot be modelled in a serially based simulation.

Experimental results will have to indicate that the concurrent processing prototypes will not behave adversely if implemented on the wider scale of scenario expected within the operational context of the TDS.

The work will consist of three main activities:

a) Determining of the applicability of concurrent processing to each of the functional components specified in the TDS Version 1 Phase 3. Selection of those system modules most likely to benefit from concurrent processing, the form that the concurrent processing should take, and the specification of a set of experiments designed to test performance of those modules in terms of their operating speed and their effect on the operational speed of the TDS Version 1 Phase 3 as a whole.

b) Construction of a set of hardware and software prototypes for implementing the recommendations of (a). Provision of additional components (hardware and software) to the TDS Version 1 Phase 3 for conducting experiments in concurrent processing. Software analysis tools to determine the degree of concurrency being exploited, use of each processing element in the concurrent processing array, traffic in each

c) Running the experiments specified in (a) under the enhanced TDS environment constructed in (b). Producing recommendations on future architectures for the KBS components of modules in the TDS.

Relation to Programme

The final results of this project are unlikely to be achieved in a timescale which will directly affect any of the other projects in the research programme. However there is a close relationship between this project and SP1.1.2 on techniques for knowledge based optimisation, SP3.1.2.1 on the use of neural networks for data fusion and SP3.1.2.5 on genetic algorithms. The examination of the C^2 problem without the constraints of an existing serial implementation will be of value in determining whether the TMD application can derive any benefit from concurrent processing.

Time and Effort

Hardware Architectures	4 my
Total	4 man years over a 3 year period.

Inputs/Assumptions

The main input to this project will be the TDS Version 1 Phase 3 and the ARE work to date in this field. The results of SP2.1.1.2 on the performance of the TDS will provide indicators of areas within the TDS where concurrent processing may be of the most value. If it is felt that concurrent processing will not enhance the TDS sufficiently in its current form, then this project may need to be terminated after activity (a). If the project proceeds, then the provision of appropriate scenario data from SP4.1.1.2 will be necessary, together with further use of the results of SP2.1.1.2 to measure and evaluate any improvements in performance.

Deliverables

- Analysis of the C^2 problem, with particular reference to the TDS Version 1 Phase 3, to assess the applicability of concurrent processing techniques to each of functions carried out in the TDS Version 1 Phase 3.
- Specification of test scenarios for testing concurrent processing prototypes.
- Hardware and appropriate software environment for the development of concurrent processing software prototypes.
- Software prototypes of implementations of concurrent processing solutions for a number of aspects of the TDS.
- Analysis of the operational speed of the TDS Version 1 Phase 3 with the introduction of concurrent processing prototypes under a range of experimental scenarios.
- Recommendations on future architectures for the TDS incorporating the use of concurrent processing.

Resources

Hardware:	Workstation £25k
	Concurrent Processing System (e.g. Meiko 32 transputer system £100k)
Software :	0 if included as part of concurrent system, £15k for a product such as Strand for building prototypes.

SP 2.1.2.4 HCI for Situation Assessment and Resource Allocation

Description

This project will investigate the processes underlying human situation assessment and resource allocation. It will produce a validated model, suitable for determining how best to provide computer-based assistance and HCI facilities for the situation assessment and resource allocation functions. An HCI suitable for inclusion in current and future situation assessment and resource allocation research projects will be built.

It is hoped to extend the TDS programme to incorporate situation assessment and resource allocation modules. These both present new and complex problems for the design of an appropriate HCI. The user will be expected to interact with the computer to a much greater extent than with the Data Fusion Module, especially in terms of joint decision making. Therefore, it is critical at the outset to form adequate models of the mutual exchange of information which is likely to take place during the situation assessment and resource allocation tasks (as opposed to modifying the outputs presented as in the DFM case). Resource allocation is likely to be an advisory system of some kind : the user will be presented with a range of options, and questions such as how many options should be presented, and in how much detail should be addressed.

Objectives

To specify, design, implement and evaluate an HCI for these two tasks will require the following objectives to be met :

- To conduct experimental and observational investigations of how operators perform situation assessment and resource allocation in the naval C^2 environment, and to build a model to describe the processes involved.
- To use the above model identify the level of computer based support needed by the operators and users of the TDS to conduct the tasks of situation assessment and resource allocation.
- To implement the appropriate levels of computer support required (i.e. construct an appropriate HCI based on the first situation assessment prototype, SAP-1 and the first resource allocation prototype, RAP-1)
- To evaluate where possible the success of the model and its implementation.
- To make recommendations on the design of the HCI for future versions of the situation assessment and resource allocation modules of the TDS.

It should be noted that these objectives and the programme of work outlined below could form the basis of an initial HCI specification and implementation for the situation assessment and resource allocation aspects of the TMD problem, though conducting observer trials to formulate the models may prove more difficult for that application.

Technical Work Involved

The core of this project will be the development of models for the decision making processes currently involved in the situation assessment and resource allocation tasks as performed on board ship. While it is possible to design a KBS system to perform situation assessment and resource allocation, the key factor in the model construction will be to derive what the human operators and users will require from any computer based support tool (i.e. user oriented design to some extent) so that they can improve on current levels of performance (e.g. in terms of speed or accuracy of decision making). It should be noted that situation assessment and resource allocation are both being tackled in this project because of the difficulty in isolating them as completely independent functions. If this project shows that this is the case to a greater extent than already assumed, then there may be implications for the overall system architecture.

The work will consist of four main activities:

a) Specifying a set of scenarios for the situation assessment and resource allocation tasks to be performed on. Presenting naval personnel with those scenarios and observing/eliciting the way they perform these tasks. A combination of the TDS, facilities at HMS Dryad, documented examples from naval exercises and possibly special simulations will be used to observe personnel carrying out situation assessment and resource allocation tasks.

b) Construction of models of the decision making processes involved in situation assessment and resource allocation tasks. The models should be sufficiently flexible to express a range of possible options (e.g. different command room teams may perform the situation assessment and resource allocation tasks in a different manner). The model should also allow for the inclusion of idealised approaches to the problem (e.g. a PWO would like to be able to make a decision based on information which is not available using current C^2 systems, but may be available in the SAP). Modelling techniques which are scale independent (i.e. regardless of the level at which the analysis is being performed the technique is the same) are attractive. The Goals Operators Methods Selection rules (GOMS) model (Card et al 1983) and the SOAR architecture (Laird 1983) are possible starting points for this task. These models will then be used to determine the partitioning of the information processing tasks between human and machine in order to achieve the overall decision making process.

c) The model developed under (b) will be used to specify the computer-based component of the HCI for the situation assessment and resource allocation tasks. The aim will be to anticipate HCI problems and issues at the design stage, and experience with the TDS to date will provide input here.

   This specification will be implemented in prototype form, using the SAP-1. Implementation issues such as the appropriate design of symbology, the representation of uncertain information, the representation of a range of alternative options, and the provision of explanation facilities will need to be considered and optimised where possible. Explanation facilities will be especially important. Since the user is closely involved in the decision making loop, they must be able to have further information if a course of action is not immediately self-evident from the initial information presented. Also, if the

systems being constructed are intended for real-world deployment and use, then the user must be able to use the system with confidence in its judgement. Providing explanations helps to build user confidence, and also provides a language in which the user can suggest improvements which can be made to the knowledge base during trials. Furthermore, not all explanations are likely to be required in an 'at peace' state. If the user has built up an understanding of the explanation process, then in situations of high-speed decision making, ways to transmit explanation information as efficiently as possible will be important. This project will produce and evaluate a number of alternative representations of explanations, with the aim of making them such that they are acceptable to the prospective users. The possibility of designing separate levels of explanation for users as opposed to operators must also be included. Other features which may not have been necessary at the DFM level such as the provision of "what-if" scenarios (i.e. the calculation of different effects on situation assessment and resource allocation under a range of alternatives) will also be included.

d) The model and implementation will undergo assessment and evaluation (although this is likely to be partial given the prototypical nature of the software). Prospective users and operators will be asked to run a series of trial scenarios using the newly developed HCI component running in conjunction with SAP-1. The ability to perform set tasks, and feedback reactions will be used to form a programme for improving the HCI.

Relation to Programme

This project will have a close relationship with all other projects specifically based around aspects of HCI such as SP2.1.1.4, SP2.1.1.5, SP2.1.1.6, SP2.1.1.7, SP2.1.3.4 and SP2.1.4.1. The prototype projects for the TMD based applied research: SP2.2.3.1 on adaptive preferential defence, SP2.2.3.2 on sensor management, and SP2.2.3.3 on the intention prediction of intelligently moving objects all have HCI components which will use the results of this project.

Time and Effort

Human Computer Interaction	6 my
Total	6 man years over a 3 year period.

Inputs/Assumptions

The main inputs to this project will be the Situation Assessment Prototype (SAP-1), and the Resource Allocation Prototype (RAP-1). These will not have been completed at the start of the project, but the specification of the HCI for those projects will have been made and will serve as the skeleton of any implementation work carried out here. Specified scenarios will need to be generated as part of the initial model building process, and at the validation stage, so input from SP4.1.1.2 is necessary. The project will not aim to change the current hardware facilities used for the displays (i.e. Sigimex displays), rather it will seek to utilise that hardware in an optimal manner. Results from other projects will generally feed into this work, e.g faster response times, new forms of knowledge representations (SP2.1.2.1, SP2.1.2.2) etc.

Deliverables

- Documented results and analysis from the observer trials and experiments based on how naval personnel perform the situation assessment and resource allocation tasks.
- Models to define the decision making processes of all levels of naval personnel involved in the situation assessment and resource allocation processes.
- Specification of the computer based component of the model of decision making.
- Prototype implementation of the specification, including facilities for using alternative symbologies, backgrounds, textual and graphical representations.
- Specification of a set of observer experiments together with appropriate criteria to evaluate the model and implementation.
- Results and Analysis of these observer experiments. Recommendations for improvements to models and implementation.
- Revised versions of model and implementation.

Resources

Hardware :	2 Workstations £50k (i.e. access to 2 terminals linked to the TDS land based system)
	Sigimex Display and Connections to Workstation £20k
Software :	Ada compiler £7k
Total :	£77k

The following skills and experience are central to the success of this project :

- operational experience at applying HCI techniques to complex C^2 domains;
- experience of HCI components with explanation and what-if facilities;
- staff with experience of KBS in the context of situation assessment.

SP 2.1.3.1 Development of Techniques for KBS Maintenance

Description

This project will investigate extensions to the KBS life cycle model and will develop prototype software tools to support the maintenance of knowledge based systems for C^2.

Objective

In order to ensure that the TDS Version 1 can be kept operational for a sufficiently long period to enable evaluation and trials to be effectively carried out, provision will need to be made to support maintenance of the sea-going system.

The objective of this project is to:

- Develop techniques and tools to support the maintenance of TDS Version 1 during its evaluation.

- Develop foundation for a more structured approach to the maintenance of further versions of the TDS and TMD.

Technical Work Involved

This research will investigate techniques to provide support for the maintenance and configuration of KBS which are already operational, albeit in a trials environment. It will develop prototype tools to enable the techniques to be used and demonstrate their effectiveness using TDS Version 1.

In addition, the research will investigate the KBS development process and propose techniques which can be used during KBS development to enhance the maintainability of the resulting KBS. Prototype tools will be required to support these techniques as appropriate and their efficacy with respect to the further TDS developments will be demonstrated.

The major technical activities to be carried out are:

1 To investigate techniques to provide support for the maintenance and configuration control of KBS which have already been developed

2 To develop prototype tools to support maintenance and configuration control of existing KBS rule-bases and to demonstrate their effectiveness using TDS Version 1. This may include porting the KB into a database to assist in the maintenance process.

3 To investigate the KBS development process and to propose techniques which provide support for future maintenance by procedures carried out during development.

4 To develop prototype tools based upon the techniques devised in (3) and to demonstrate their efficacy with respect to further developments of TDS.

Relationship to Programme

Although no explicit dependencies with other SANDERLING projects can be identified, many projects, especially those in Category 2.1 are dependent upon the continued satisfactory status of the TDS Version 1. This work can thus be seen as highly significant to the success of major parts of the programme. The results of this project will also be directly relevant to the TMD programme.

Time and Effort

4 man-years over 2 years.

Inputs and Assumptions

Assumes the availability of the TDS knowledge base as an input.

Deliverables

Deliverables from the project will be:

- Techniques to provide support for the maintenance and configuration control of operational KBS and recommendation for implementation phase.
- Guidelines for a policy for the maintenance of KBS.
- Prototype tools to support techniques recommended in (1) and demonstration of their efficacy using the existing TDS.
- Analysis of KBS development process and proposing techniques which provide support for maintenance by carrying out extra actions during development.
- Prototype tools based upon the recommendations of (3) and a demonstration of their efficacy with respect to the enhanced TDS.

Resources

Hardware:	2 x AI Workstations	£50k
Software:	2 x AI Language	£10k
Total:		£60k

The following skills and experience are central to the success of this project :

- experience of supporting operational and frequently modified KBS;
- sufficient application and technical grasp to be able to assess the rate of change of different areas of knowledge in a sea-going system;
- experience of techniques for re-structuring KBS in the light of application changes;

- awareness of the KBS development cycle;
- familiarity with tools to support the KBS life-cycle (both commercial products and those that are still under development or at the proof-of-concept stage);
- awareness of KBS development life-cycle and maintenance techniques.

SP 2.1.3.2 Investigation of Techniques for Knowledge Acquisition

Description

The knowledge acquisition techniques which have been developed to date, eg repertory grids etc., have tended to concentrate on the declarative elements of knowledge, ie objects, relationships etc. As such they fail to address many aspects of procedural knowledge and are inadequate for the extraction and represention of the concepts involved in spatial and temporal knowledge. This project will identify knowledge acquisition methodologies and tools for applications with a spatial and/or temporal component. This may involve extending or adapting existing techniques, and evaluating their potential using further developments of the TDS.

Objective

In order to support the development of future enhancements of the TDS there will be a need to carry out knowledge acquisition in domains with a temporal or a spatial component. The objectives of this project are:

- To develop a methodology for knowledge acquisition for problem domains with a spatial and temporal components.
- To evaluate the effectiveness of the methodology with respect to further developments of the TDS and related projects, including SAP, RAP and the TMD programme.

Technical Work Involved

To investigate techniques for knowledge acquisition in problem domains involving spatial and temporal knowledge.

The major technical activities to be carried out are:

1. Generate model scenarios, involving systematic variations in the spatial and temporal components.
2. Conduct interviews with experts and derive initial models of the domain.
3. Investigate the applicability of current knowledge acquisition techniques and tools to such problems - to extend and adapt them as necessary.
4. Experiment with alternative representation schemas, eg temporal logics, and define techniques for the elicitation of knowledge-based on them.
5. Define the elements of a methodology incorporating the best elements of all the approaches.
6. Evaluate the methodology using further developments of TDS Version 1.

Relationship to Programme

It is expected that reasoning about temporal and spatial knowledge will play a significant part in further developments of the TDS programme, for example in situation assessment in SP2.1.2.1, it is therefore important to a number of future activities within the programme that a greater understanding of knowledge acquisition in such domains is achieved.

Time and Effort

3 man-years over 1.5 years.

Inputs and Assumptions

This project assumes that access to on-going application development as part of the TDS enhancement aspects of Category 2.1 can be achieved in order to enable the methodology evaluation to take place. It also assumes the availability of appropriate experts in the naval domain.

Deliverables

Deliverables from the project will be:

- Analysis of the problems inherent in knowledge acquisition for problems involving spatial and temporal knowledge.
- Methodology for knowledge acquisition for problems involving spatial or temporal knowledge.
- Evaluation of effectiveness of methodology proposed in (3) and (4) when applied to aspects of further TDS development.

Resources

Hardware:	1 x AI Workstation	£25k
Software:	1 x AI Language	£5k
Total:		£30k

SP 2.1.3.3 Development of Methods and Tools for the A Posteriori Validation of KBS

Description

This project is concerned with the development and assessment of techniques for the *a posteriori* validation of real-time KBS, using the TDS Version 1 knowledge base as a testbed. *A posteriori* validation refers to validation which is carried out after the system development process has been completed. This is recognised as a fundamentally difficult task, since the performance of the final system cannot always be related back to a coherent expert model. However, some progress has been made in the area, eg in Esprit project VALID, and this project should build on that work.

Objective

In order to deploy KBS with a sufficient degree of confidence it will be necessary to carry out a validation process upon the knowledge base and to evaluate the significance of the results of that validation process.

The objective of this project is:

- To devise techniques for the *a posteriori* validation of KBS.
- To use those techniques to validate aspects of the TDS Version 1 knowledge base.
- To define the limits of *a posteriori* validation of KBS.

Further work in SANDERLING project SP2.2.2.2 extends the range of techniques to cover *a priori* validation, ie. validation which takes place during the KBS development process.

Technical Work Involved

The major technical activities to be carried out are:

1 Investigate existing techniques for the *a posteriori* validation of real-time KBS.

2 Extract a functional sub-set of the TDS for experimental analysis.

3 Define a set of model scenarios and parameterise these in terms of complexity, and coverage of the domain.

4 Run the TDS sub-set against the scenarios and evaluate using metrics derived from project SP2.1.1.2

5 Interview experts to assess the results of the exercise and define a set of validation techniques based on that analysis.

7 Where appropriate, develop tools to support a selected set of validation techniques.

8 Apply to the TDS.

Relationship to Programme

This project serves to validate aspects of the TDS Version 1 knowledge base and as such serves as a central activity which is paramount to the success of the whole programme.

Time and Effort

3.5 man-years over 18-months

Inputs and assumptions

This project assumes the following inputs :

- The availability of the TDS Version 1 knowledge base as a testbed for the validation and verification techniques devised.
- Access to scenarios and ARE experts.
- The performance and competence metrics from SP2.1.1.2

Deliverables

- Techniques which enable *a posteriori* validation of knowledge bases and identification of most appropriate techniques for use in TDS Version 1 validation.
- Prototype tools to support use of identified techniques and results of validation of TDS Version 1 KBS using techniques.
- The results of the application of the techniques to the TDS.
- Recommendations on the limitations of *a posteriori* validation techniques for KBS.

Resources

Hardware:	1 x AI Workstation	£25k
Software:	1 x AI Language	£5k
Total:		£30k

SP 2.1.3.4 Exploration of Techniques for Explanation in Situation Assessment Systems.

Description

This project will use the Situation Assessment Prototype (SAP) to explore the design of explanation facilities for supporting the production of tactical picture displays. The work will include an analysis of the explanation requirements of operators, and an investigation of alternative methods for the display of explanations.

Objectives

The provision and use of explanation facilities is acknowledged as an essential pre-requisite for most expert systems. It is often given insufficient consideration in the development cycle, system developers having less need for such high-level assistance. This project has the following objectives:

- To extend the work done to date at ARE (Montgomery89) on the development of a graphical explanation facility, specifically to produce explanation facilities for use with the situation assessment module of the TDS.
- Ensure that the proposed explanation facilities integrate with the other work on the development of the HCI for the TDS system.
- To produce explanation facilities which allow for the representation of and reasoning under uncertainty as a key component of the inference system of the SAP.
- Conduct a series of human factors experiments designed to elicit reactions to various methods of explanation from prospective users of the SAP.
- Make recommendations on the form of explanation facilities for future modules of the TDS.

Technical Work Involved

The proposed TDS and TMD systems have two characteristics which make it critically important that the role, nature and representation of explanations be addressed. First they are extremely complex systems; no user will be able to understand every conclusion that they are likely to be presented with. Although most conclusions may be acceptable and non-critical, if the user is involved in the decision making loop, then they must be able to have further information if a course of action is not immediately self-evident from the initial information presented. Second is the issue of user acceptance. If the systems being constructed are intended for real-world deployment and use, then the user must be able to use the system with confidence in its judgement. Providing explanations helps to build user confidence, and also provides a language in which the user can suggest improvements which can be made to the knowledge base during trials. Third, not all explanations are likely to be required in an 'at peace' state, if the user has built up an understanding of the explanation process, then in situations of high-speed decision making, ways to transmit explanation information as efficiently as possible will be important. This

project will produce and evaluate a number of alternative representations of explanations, with the aim of making them such that they are acceptable to the prospective users. It should be noted that each of the above arguments apply to both users (command level) and operators (weapons officer level) alike, and separate explanation facilities may need to be be constructed according to their respective needs.

The work will consist of three main activities:

a) From reference to current system specification and implementation, together with interviews with prospective users, specify the expected role, nature and possible forms of explanation facilities in the situation assessment module.

b) Implementation in prototype form as part of SAP-2 the explanation facilities specified in (a).

c) Using (b) to run a series of observed operator sessions to determine the efficacy and efficiency of the different forms of explanation facility. To run experiments specifically designed to test the role of the explanation facility for an inference engine which incorporates uncertainty. To observe the role of the explanation facility in getting the user to express disagreement (and hence modify) the knowledge in the system.

d) To use the results of (c) to make recommendations about the form of explanation facilities for future modules of the TDS

Relation to Programme

The results from this project will be of use in providing appropriate explanation facilities for the in all future KBS based modules for either the Naval, or TMD applications.

Time and Effort

Human Computer Interaction	2 my
Total	2 man years over a 2 year period.

Inputs/Assumptions

The main inputs to this project will be the SAP. Early results from the enhancement of the SAP in SP2.1.2.1 will be useful. Experimentation with alternative forms of representing explanation will use the results of SP2.1.1.5, and the frequency with which explanations are required will be a component of SP2.1.1.6. The project is also related to work on knowledge acquisition (SP2.1.3.2), knowledge base maintenance (SP2.1.3.1), and the validation of knowledge bases (SP2.1.3.3). It is possible to consider the use of adaptive explanation facilities (SP2.1.4.1), and the resulting explanation facilities will form a central part of any training programme (SP1.1.3, SP3.1.2.5), and all KBS related implementations and prototypes within the research programme should derive some benefit from this work (e.g. SP2.2.3.2 on a prototype for sensor management for the TMD application) . Access to users for interviewing on their expectations of explanation facilities and for experimentation is required.

Deliverables

- Specification of role, nature and potential form of explanations within the situation assessment problem.
- Software prototypes to integrate with the current version of the SAP, capable of producing a number of alternative explanation facilities.
- Analysis and evaluation of the success of the explanation facilities through observed user trials and experiments.
- Recommendations on the implementation of explanation facilities for all KBS modules in the TDS and TMD research programme.

Resources

Hardware:	Workstation	£25k
Software :	Ada Compiler	£7k
Total :		£32k

SP 2.1.4.1 Exploration of Adaptive Interfaces for C^2 systems.

Description

This project will investigate the opportunities for the design and prototype implementation of a KBS to facilitate and improve the quality of the HCI component of the TDS system.

Objectives

The aim of this project is to evaluate the potential for enhancing the MMI of C^2 systems through the use of KBS, specifically to investigate the design and application of adaptive interfaces in KBS-based C^2 systems. It will do this through the use of the HCI component of the TDS Version 1 Phase 3 as a vehicle for experimentation and prototype implementation of an adaptive interface. The objectives of the project will be:

- To determine a set of operating conditions which justify the need for an adaptive interface in a C^2 system.
- To produce profiles of the types of operators and users of the TDS. To determine the number of different stage of development in learning to use the TDS from novice to skilled operator/user.
- To evaluate the suitability of each of the constituents (e.g. symbology, menu format and contents, window size and contents, explanation facility, input language etc.) of the HCI component of the TDS Version 1 Phase 3 to the inclusion of an "adaptive" component.
- To prototype a knowledge-based system for evaluating and implementing an adaptive sub-component of the HCI component of the TDS Version 1 Phase 3.
- To conduct a small-scale observer experiment designed to assess the added value obtained from the prototype adaptive interface.
- To establish possible future requirements for the specification and implementation of adaptive interfaces.

Technical Work Involved

The TDS has an HCI component which is based on a user requirement specification of system tasks that the TDS operators and users would have to perform. However, there are aspects of the TDS implementation and proposed use which make it impossible to either anticipate every task or operational situation that the TDS will be in, or to display the vast amount of information that the TDS (as an example of a large scale KBS) can display at any one time. No single format of HCI could allow for all these alternatives, so current design practice is based on a version which will offer the most utility for the majority of the time. The introduction of an adaptive component into the HCI expands the potential use of the TDS. The work will attempt to isolate those aspects of the HCI which are most suited to the introduction of an adaptive component, and then implement that adaptive component in prototype form.

The work will consist of three main activities:

a) Determining the applicability of the C^2 problem to the use of an adaptive interface. A number of areas will be addressed : would the HCI need to adapt for a range of different users from novice to expert, and to what extent might the HCI be made to adapt to the personality or prejudices of a particular operator or user?; Should the HCI be sensitive to the general status of conflict and adapt automatically ?; could changes in environment conditions mean that the HCI should change ?; to what extent could the TDS dynamically calculate the partitioning of tasks between man and machine and present /request information accordingly ? Attention will be given to prospective operator and user reactions to the ideas behind adaptive interfaces; will an adaptive interface significantly increase the amount of training, will it lead to too low a operator/user involvement with the system, will it increase the user acceptability and usability of the TDS etc.?

b) Identification of possible constituents of the HCI of the TDS Version 1 Phase 3 (or possibly the SAP-1 or RAP-1 if complete) that could benefit from the introduction of an adaptive capability. This will be based on the results of (a), the results from the experimental evaluation programme, and an evaluation of what the state of the art can contribute (e.g. adaptive natural language interfaces would not be possible in the timescales). This task will also define the nature and content of the adaptive interface. A key question will be to whether the system will be able to monitor the users behaviour and the general state of the world and adapt accordingly, as opposed to asking for specific input from the user to enable adaptation to take place.

c) Applying existing and novel adaptive interface techniques to implement small-scale software prototypes illustrating the possible use of an adaptive interface. These prototypes would be informally evaluated and modified through a series of presentation to operators/users, and comparison with the HCI component of the original system (TDS, SAP,RAP).

Relation to Programme

This project will not produce results in time for them to be used by other projects in the course of the research programme, and is seen as making a contribution to the longer term view of what the HCI for C^2 systems will need to be. The use of adaptivity is strongly related to the work proposed in SP3.1.2.4. on Intelligent Training Systems.

Time and Effort

Human Computer Interaction	1.5my
Total	1.5 man years over a 18 month period.

Inputs/Assumptions

The main inputs to this project will be the HCI component of the system chosen for the prototype implementation of an adaptive interface (either TDS Version 1 Phase 3, SAP-1 or RAP-1). The TDS Version 1 Phase 3 will be preferable due to the extensive evaluation and assessment work carried out in projects SP2.1.1.2, SP2.1.1.3, SP2.1.1.6 and SP2.1.1.7.

Deliverables

- Review of the potential for introducing adaptivity into C^2 systems.
- Profiles of prospective operators and users of the TDS system.
- Identification of the those parts of the HCI component of the TDS Version 1 Phase 3 (or SAP-1/RAP-1) suitable for an adaptive capability.
- Software prototypes for illustrating the use of adaptive interfaces (including the knowledge bases used in their construction).
- Results and analysis from informal observer experiments
- Recommendations for the use of adaptive interfaces in the HCI for future C^2 systems

Resources

Hardware: shore	Workstation	£25k (i.e. access to one terminal on the TDS based facility)
Software :	Ada Compiler	£7k
Total :		£32k

Access to prospective users for informal evaluation will also be required.

SP 2.1.4.2 KBS for Amphibious Operations Support

Description

This project is intended to provide further support for work in command and control of Amphibious Operations.

Objectives

A programme of work has already commenced in onload (stowage) and offload planning, message handling in the command post and support for helicopter tasking for amphibious operations. The intention here is to extend this work to further functions by creating an integrated set of planning systems that address:

1. The off-loading problem. This is related to the on-loading (stowage) problem but needs to account for any changes in plans that have taken place during the voyage and any new knowledge on the conditions at the landing site.

2. Tactical mission planning. Given a site, or selection of sites at which to stage a landing the planner must select the best places to land men and vehicles and the best timing for such action.

3. Once the force is disembarked, a planning support system is required to assist land/sea based activities e.g. inshore ship defence, logistic support, naval gunfire support etc.

The Tactical Plan acts as input to both stowage and disembarkation planners, it presents them with the goal state.

Technical Work Involved

Overview

There are very substantial differences between the planning of amphibious assaults and other areas of naval command and control. Here the objectives are to move large quantities of men and machines to predefined landing sites for land-based operations. This planning process must consider a large number of different, but obviously inter-related, aspects:

- the number of men and vehicles to be delivered to the landing site, and for what purpose;
- the geographic structure of the area of operations, for the choice of appropriate landing sites;
- distribution of enemy forces in the landing zone;
- movement of vessels around the landing area , eg. for access and exit, and the timing of these;
- support activities such as the provision of air cover or naval ship-to-shore bombardment;

- logistic support for the land forces after disembarkation.

The tactical planning of the assault leads to a requirement in terms of the type of vehicles to be offloaded and their sequencing. These requirements are expressed in the form of tables such as the Ship Loading Table, Landing Priority Table, Surface Assault Schedule and the Helicopter Employment Assault Landing Table. As the mission progresses more facts become known about enemy position, beach site suitability etc. This results in an iteration between the various planning processes as the assault plans are evolved and developed, this occurring during transit from the home base to the offload areas. The actual offload takes place over a number of days during which the land-based operational command post is set up. When the chop command occurs, amphibious force command and control is exercised in the land-based command post. This requires communications between ship and shore as well as an amphibious support system to be resident in both the ship and command post. Significant interaction occurs between the ship's command and control system and the command post. This is required to ensure, for example, adequate air cover to protect both land-based and ship-based amphibious assets.

Research Components

1. Development of tactical assault planning system. This to include the functions of air cover support, naval ship to shore bombardment and logistic support as well as integration of the disembarkation planner. The planning processes here all involve spatial/graphical reasoning based upon geographic information (both land and water). Integration of the many components of knowledge in the process described above needs to be understood, and mechanisms for acquiring and storing this data for each planning task need to be developed.

2. Design and development of disembarkation planner. This is by far the simpler of the two tasks, requiring the development of a system to map the vehicle and manpower configuration developed by the stowage planner onto the required landing sequence.

Relation to Programme

To a large extent this project, or series of projects, is independent of the research programme's mainstream work in on-line command and control. There will be aspects of other research work that are applicable, for example the principles of resource allocation will be similar, but guided by a different form of plan.

Work in the mainstream naval programme is expected to address the efficient storage of spatial data (see for example SP2.1.2.1, the "Enhanced Situation Assessment Prototype"). This will be a necessity for the tactical planning element of this project where geographic structure is an important consideration in determining appropriate landing sites. There are aspects of the amphibious assault planning processes that will require different primitives to other command and control problems, i.e. existing representations will form a subset of those needed here.

Time and Effort

Note that, due to some uncertainty over the source of funding for this work, these estimates represent around 50% of the effort anticipated to be needed to reach a pre-

production prototype stage of system development.

Knowledge Representation and Manipulation	4.5 My
Total	4.5 My over 2 years

Inputs / Assumptions

The implementation mechanisms adopted for the disembarkation planner will need to be considered in designing the other modules, since they will have to interface to it.

Access to operational experts, ie. Royal Marines personnel, will be necessary for elicitation of expertise and evaluation of systems. While some access can be gained through ARE, preference would be for contractors with appropriate personnel on staff.

Deliverables

The deliverables are:

- Prototype disembarkation planner incorporating all already developed prototypes.
- Prototype tactical assault planning system, including incorporation of spatial data (land and sea).
- Prototype integrated planning system incorporating both of the above.
- Knowledge bases for the above.

Resources

Hardware and software platforms for the planners have yet to be decided upon. A budget of £25k should be anticipated for hardware purchase, and a further provision should be made of £15k for purchase of an appropriate development toolkit to support the work.

SP 2.2.2.1 The Specification of KBS for Command and Control Applications

Description

Specification of KBS is currently a vague and unsatisfactory process, often being a successive iteration process whereby the developer's and user's expectations gradually reach a point of equilibrium.

This project is concerned with investigating the specification of a real-time KBS in the C^2 domain, by using the Development Methods Prototype (SP2.2.3.4) as a test vehicle. Particular consideration will be given to the role of a KBS life-cycle model in the specification process and the specification of speed, accuracy and performance requirements. In addition consideration will be given to the production of test specifications for KBS applications to C^2.

This project is not intended to address the feasibility of using formal methods to specify a KBS : this is addressed by SP3.1.2.3.

Objective

The objective of this project is:

- To establish techniques for the specification of KBS in the C^2 domain. in particular the specification of speed, accuracy and performance requirement.
- To establish techniques for the production of test specifications for KBS applications to C^2 applications.
- To provide input to MOD/DOD guidelines for KBS procurement.

Technical Work Involved

The major technical activities to be carried out are:

1 Identify approaches to the specification of KBS which should be assessed for specifying command and control KBS.

2 Investigate appropriate techniques for the analysis of the application domain of the DMP, to identify the role of KBS within the overall problem-solving task. This would include consideration of the information processing characteristics of sub-tasks, the availability of suitable expertise, and the interfaces between KBS and other components of a system.

3 Investigate the feasibility and efficacy of techniques identified in (1) by using them to generate an initial specification of the KBS components of the Development Methods Prototype. During the early phases of the development cycle, the project will then explore appropriate techniques, eg rapid prototyping, for refining and validating the initial specification.

4 Analyse which specification procedures which should be incorporated on an experimental basis in future KBS procurement activities.

Relationship to Programme

Given the current state of the art of KBS specification it is unreasonable to expect that this project can provide major input to other activities in the timescales of the programme. The project will need to have access to the Development Methods Prototype developers and be involved in the design and implementation of the prototype in order to evaluate the effectiveness of the techniques proposed. This project is closely related to the work on validation in SP2.2.2.2, and it is anticipated that many of the techniques developed will be common to the two projects.

Time and Effort

2.5 man-years over 18 months

Inputs and Assumptions

This project assumes access to the development of the Development Methods Prototype (SP2.2.3.4) in order to investigate the practical effectiveness of the specification techniques identified.

Deliverables:

Deliverables from this project will be:

- Investigation of those KBS specification techniques which are most appropriate to specifying real-time C^2 applications.
- Results of experimental use of the techniques identified to specify aspects of the Development Methods Prototype.
- Recommendation of those techniques which should be used on an experimental basis for future ARE KBS procurement exercises.

Resources

Hardware:	AI Workstation	£25k
Software:	AI Language	£5k
Total:		£30k

The following skills and experience are central to the success of this project :

- analytical expertise especially at partitioning applications into KBS/non-KBS components;
- expertise in the development methods field, and specifically the overall place of specification within the KBS life-cycle;
- experience of implementing systems employing a wide range of different techniques (eg. Formal Methods, cross-compilation techniques) that may influence both the form and process of KBS specification;

- staff with an understanding of SDI/TMD scenarios;
- staff with extensive KBS development experience.

SP 2.2.2.2 Verification and Validation of 'Safety Critical' KBS

Description

This project will investigate techniques for the *a priori* validation of command and control applications of KBS and explore their effectiveness in relation to the Development Methods Prototype (SP2.2.3.4). The term *a priori* validation is used to refer to validation which is carried out during the development process of the KBS.

Objective

This project follows on from SP2.2.2.1 and will aim to develop techniques for the *a priori* validation of real-time KBS. In order to achieve this some form of specification will be a necessary prerequisite and so the completion of SP2.2.2.1 is a necessary input.

The objectives are:

- To identify and devise techniques which can be used to support the *a priori* validation of command and control applications of KBS.
- To validate aspects of the Development Methods Prototype using the techniques identified.

Technical Work Involved

The major technical activities to be carried out are:

1. To investigate techniques for the *a priori* validation of command and control applications of KBS.
2. To investigate the effectiveness of the techniques identified in (1) by using them to validate aspects of the Development Methods Prototype. The emphasis in this project will be on the application of appropriate techniques during the development cycle. These may include mechanisms for establishing effective intermediate representation languages as the basis of validation protocols. Controlled experiments will be carried out to explore the value of these techniques in establishing the validity of the Prototype during its development.
3. To implement prototype tools to support the validation methods where appropriate.

Relationship to Programme

This project serves to validate aspects of the Development Methods Prototype knowledge base during the development process and as such serves as a central activity which is paramount to the success of the whole programme. It is also anticipated that the results of this project will feed back into the Specification work in SP2.2.2.1.

Time and Effort

6 man-years over 2 years

Inputs and Assumptions

This project assumes the availability of the results of SP2.1.3.3: Methods and Tools for *A posteriori* Validation of Knowledge-based Systems and access to the development process of the Development Methods Prototype to a sufficient degree to permit the evaluation of the *a priori* validation techniques being investigated within this project.

Deliverables

Deliverables from this project will be:

- Techniques for the *a priori* validation of command and control applications of KBS.
- Analysis of the effectiveness of the application of the techniques to certain aspects of the Development Methods Prototype.
- Results of using the techniques to carry out validation of the Development Methods Prototype.
- Prototype software tools to support the selected validation methods where appropriate.

Resources

Hardware:	2 x AI Workstation	£50k
Software:	2 x AI Language	£10k
Total:		£60k

The following skills and experience are central to the success of this project :

- experience of applying KBS Validation and Verification techniques to the defence sector;
- experience of how techniques to ensure safety critical performance can be fitted into the life-cycle model;
- application and theoretical knowledge on the problems real-time and C^2 presents to KBS implementation;
- experience of applying *a priori* validation and verification techniques;
- staff with an understanding of SDI/TMD scenarios.

SP 2.2.2.3 Investigation into the Robustness of KBS architectures

Description

This project will explore the robustness of the KBS Architecture of the Development Methods Prototype (SP2.2.3.4) and recommend the best means of providing robust KBS.

Objective

The objective of this experiment is to determine the best means of designing robust KBS and to highlight the weaknesses in the current system.

Technical Work Involved

The work will involve experimenting with the Development Methods Prototype (DMP) to identify the weak areas of the system. Software trials will be undertaken to investigate ways around these problem areas and from these trials a set of generic design principals and specific implementation recommendations will be made.

The robustness of the KBS architecture will be considered from a number of aspects:

- The absolute robustness of the architecture of the DMP from the point of view of being 'crash proof' or never 'hanging'.
- The ability to withstand attempts by the naive, malicious or just curious operator to perform actions which the designer had not intended, and cause the system to malfunction. The HCI should trap out, through primary and secondary levels of input validation, the majority of invalid keyboard actions. The tertiary level usually causes database interaction, and the DMP should be resilient to this. The HCI should remain friendly during this interaction and the interface should never 'hang'.
- The knowledge base should be capable of modification and should remain resilient whilst retaining its performance. The system should not be so highly tuned such that the modification effects resilience accuracy or speed of response.
- The DMP should be scalable to meet a worst case real world scenario without loss of resilience, speed or accuracy.

Since the hardware will be commercially supplied, this research will not consider the hardware aspects of the system architecture. There are three main levels to the work :

1) Correct hardware/software paradigms. The investigation of the DMP with respect to its handling of worst case scenarios and the type of hardware/software paradigm that may be necessary to provide an assured response from the system within identified time constraints.

2) Structural resilience of the system. An assessment of the extensibility of the system in terms of its capacity to absorb modifications without compromising performance and robustness in ways that are not envisaged. This component

will concentrate on different levels of functional and structural change to the system with a view to providing computer guidance to the system modifier. Certain changes may require structural modification of a type not obvious to someone without a clear understanding of the factors that have resulted in the system being where it is in the performance envelope. Different architectural solutions to KBS problems will be trialled in software.

3) Easily understood developer and end-user interface. It may be necessary to shield the person modifying the system from some of its complexity in order to present the impact of any change to him in a form that is easily understood. Robustness of the end-user interaction must cover the communication of complex relationships and data that might compromise reliability, or lead to confusion in the user's mind.

Relationship to programme

This project has links with many other parts of the research programme. The requirements for maintainability relate to the work in SP2.1.3.1, and the design of robustness into a KBS architecture will have an impact on the validation procedures developed in SP2.2.2.2. The provision of systems with a secure maintenance path as well as a high degree of user friendliness is a requirement that may result in fundamental decisions on the acceptability of different technical and theoretical approaches in many of the application projects.

Time and Effort

2 man-years over 2 years

Inputs / Assumptions

Access to the Development Methods Prototype from SP2.2.3.4.

Deliverables

Software trial results on KBS robustness that :

- identify weaknesses in the Development Methods Prototype
- recommend an appropriate hardware/software paradigm
- provide design principals for protecting both the developer and the user from interactions that would have unexpected effects
- provide specific implementation recommendations to avoid problem areas

Resources

Access to the Development Methods Prototype hardware and software for testing its resilience.

Availability of the hardware and software to perform trials.

SP 2.2.2.4 Operational Adaptivity of Knowledge Bases

Description

This project will investigate the feasibility of enabling adaptivity of KBS-based C^2 systems in the field.

Objective

The objective of this project is to investigate the adaptability of an operationally deployed system to changes "in the field". It is envisaged that, as an engagement develops, an adversary could begin to guess one's own KBS-based tactical decisions. A commander may feel it to be tactically beneficial to replace some doctrinal or encyclopedic rule base with new rules "made on the fly". Such a change could be as catastrophic as the alternative of being predictable to the enemy. However the project will investigate ways that rules could be changed by the user so that they are fully and completely composed and specified through the HCI together with the supporting validation.

Such a revised rule base must be as complete and as unambiguous as the rules they replace. If an explanation is required in a KBS interrogation, then the explanation rule-set must also be incorporated.

Technical Work Involved

The research will investigate the feasibility of using machine learning techniques to enable in situ maintenance of KBS. It will also consider the tools necessary to support the development of an alternative rule set.

A further part of the research will also consider he implication of such system adaptivity for validation and verification.

The major technical activities to be carried out are:

1 Identify an appropriate prototype system from section 2.2.3 of the programme to act as a test-bed for the project . Analyse the KB and define the scope and limitations of "allowable" changes.

2 Investigate appropriate display paradigms to represent the range of legal changes and the implications in terms of system performance.

3 Implement an experimental HCI, based on (2).

4 Carry out a series of controlled experiments to modify the knowledge base of the prototype, monitor and carry out an evaluation of the KB before and after the modifications.

5 Analyse the results of (4) for consistency and validity.

6 Investigate the feasibility of allowing adaptivity of KBS-based C^2 systems whilst in operation by using machine learning techniques.

7 Generate guidelines on :

- defining allowable changes to KB C^2 systems.
- Techniques for safe and controllable change.

Relationship to Programme

This project serves to investigate the operational adaptivity of KBS-based C^2 systems and as such is influential on both the future TDS developments and the TMD research programme.

Time and Effort

4 man-years over 1 year.

Inputs and Assumptions

This project assumes the availability of an appropriate prototype and suitable scenario data in order to satisfactorily demonstrate adaptivity of the rule base.

Deliverables

Deliverables from this project will be:

- Analysis of the feasibility of adapting KBS-based C^2 systems in operational use, including the techniques which could be used and the problems involved,using the Development Methods Prototype as a reference model.
- Software demonstration of rule-base adaptivity, using the Development Methods Prototype and scenario data. Evaluation of results.

Resources

Hardware:	AI Workstation	£25
Software:	AI Language	£5
Total:		£30k

SP 2.2.2.5 Integrating Knowledge Representations

Description

This project is aimed at developing a consolidated representation scheme for the diverse mechanisms designed within application projects for temporal, spatial, modal and uncertain knowledge and data.

Objective

The objective of this project is the design of a single representation language and inference system for command and control problems.

The issues to be addressed in the development of a common language for diverse entities such as spatial, temporal, modal and uncertain characteristics of a domain are:

- Efficiency, and its tradeoff with expressive power.
- Storage of expressions in the language and mechanisms for retrieval.
- The representational primitives, syntax and semantics of the language.

Technical Work Involved

Overview

A common form for representation schemes is needed for consistency and completeness of database and knowledge base structures. It is important to be able to express (un)certainty about spatial and temporal entities and beliefs. Similarly, representation of beliefs will necessarily apply to information about spatial and temporal quantities. A track prediction, for example, represents a path through space that will develop over time; alternative beliefs about the identities of objects could lead to several qualified track predictions.

Capturing such relationships in a uniform and consistent manner requires detailed design of a language. This must be done with reference to the types of entity or quantity descriptions that are needed in the application domains, the knowledge that exists about them and experience with the design of representations stemming from the application projects themselves.

Research Components

1. Knowledge Representation and Manipulation

Collection of data on representation requirements from application projects and evaluation of existing attempts at representation development and integration within those projects.

Several projects in both TMD and Naval areas involve a considerable contribution by way of Knowledge Representation development. Each of these projects addresses the domain characteristics that dictate the types of thing that need to be represented. The intention is to review the Knowledge Representation work done in the major projects

of this type (see below).

2. Knowledge Representation / Real-Time Systems Design

Design of a representation language or languages covering the scope dictated by the above requirements and with commonality in mind. Testing ideas by hand-development of representation structures in the language for cases selected from application project experiences.

This is a highly complex task and requires knowledge of the capacity for implementation of logical, procedural or frame-based schemes and the epistemological strengths and weaknesses of each approach. Efficiency will be a major consideration for the practical adoption of any approach.

3. Database/Knowledge Base Interaction

Refinement of representation system for storage within a Knowledge Base Management System designed for inference optimisation. The KBMS will allow integration of inference and search processes on commonly represented data and knowledge.

Relationship to Programme

There is a strong dependency between this project and the application directed work that is investigating the representation requirements in both naval and TMD domains. For this reason it needs to follow work in projects such as SP2.2.3.1 "Demonstration of Adaptive Preferential Defence with Interactive MMI" and SP2.1.2.1 "Enhancement of the Situation Assessment Prototype" which establishes those requirements and proposes specific representational approaches.

The project should be viewed as a high priority enabling subject for research beyond the three-year period covered by the SANDERLING Programme, for example towards a Battle Management Prototype.

Time and Effort

The project will take nine months to complete, at a cost of £180k, consuming twenty-seven man-months of effort. This effort is allocated between technology stream as follows:

Knowledge Representation	1.5 My
DB/KB Interaction	0.5 My
Real-Time Systems Design	0.25 My
Total	2.25 My

Inputs / Assumptions

Input is required from several other projects describing the representational needs and approaches for the specific domain characteristics they are tackling (see above). Where possible, the software that implements the representation languages should be

made available from those projects for detailed study.

Deliverables

- proposal for a representation language or languages suitable for development of a Battle Management Prototype.

(N.B. : While experiments will have been conducted on combining representations, a software implementation of the proposed language is not a deliverable. A decision needs to be taken as to the best route to implementing the language, for example, whether or not it should be built in ADA for use within the TDS or TMDD environments).

Resources

Hardware:	AI Workstation	£25k
Software:	AI Language	£5k
Total:		£30k

These hardware and software resources should already be available at any appropriate contractor's site. It is not expected that ARE will need to purchase them; this work can be done at the contractor's site.

SP 2.2.2.6 Development of KBS not based on 'Expert' Knowledge

Description

This project will investigate the issue of developing a KBS for which there is only limited human expertise.

Objective

In a number of circumstances it may be necessary to consider the development of a knowledge-based system for a problem domain for which there is only limited human expert, a particular example of this problem is the TMD data fusion problem. In cases such as this a number of possible approaches exist including extrapolation from existing expertise from a similar problem, model-based reasoning or machine learning.

The objective of this project is to devise techniques which could be used for knowledge acquisition and validation in such application domains.

Technical Work Involved

In certain situations there is a requirement to develop KBS for problems for which there exists no corpus of human experiential knowledge as is usually the case (ie there are no human experts), for example, diagnosis of faults in a new piece of equipment. In cases such as this there is little understanding of either suitable methods for knowledge elicitation and acquisition or the implications for validation of the resulting KBS.

This project is a study into the feasibility of developing "knowledge-based" systems by a combination of alternative techniques.

The major technical activities to be carried out are:

1. Investigate methods for knowledge acquisition and validation which could be used in the development of the Development Methods Prototype (SP2.2.3.4), identify the most appropriate approach.

2. Establish the extent of background, or declarative knowledge which exists about the domain, and assess the feasibility of deriving a qualitative model of the domain.

3. Design a qualitative model of the domain.

4. Identify inadequacies and inconsistencies in the model, and assess the extent to which these could be overcome by extended simulation exercises.

5. Investigate appropriate machine learning techniques for extracting heuristic principles the simulation exercise.

6. Evaluate the effectiveness of selected methods in relation to the Development Methods Prototype.

7 Generate recommendations on the applicability of these methods, highlighting the major sources of error and incompleteness.

Relationship to Programme

This project if successful will serve as useful input to further developments of TMD systems.

Time and Effort

1 man-year over 9 months

Inputs and Assumptions

This project assumes access to the Development Methods Prototype developers and access to experts in related data fusion and situation assessment domain (ie Naval).

Deliverables

Deliverables from this project will be:

a) An initial evaluation of techniques for the development and validation of KBS for which no domain expert exists and analysis of the most appropriate technique for use in the Development Methods Prototype.

b) Recommendations on the capabilities and limitations of these techniques, and the validation issues which they pose.

Resources

Hardware:	AI Workstation	£25k
Software:	AI Language	£5k
Total:		£30k

SP 2.2.2.7 Real-Time Integrated Databases

Description

Investigation of requirements for real-time database management in TMD systems.

Objective

The objectives of the research are:

- Identification of scope of database usage for chosen TMD scenarios.
- Recommendation on database structuring and access mechanisms.
- Demonstration of mechanisms.

Technical Work Involved

Databases are used in two main roles in Knowledge-Based Systems: as working memory for such things as track data and as backing storage for encyclopædic or geographic information. The compromise to be drawn is between speed of access on the one hand and volume of data to be stored on the other. The balance between the two changes continuously with increasing performance of main memory storage; for example it is possible to contemplate holding twenty megabyte databases in main memory with current technology. Typically, working memory databases have been small and would be indexed in a simple fashion; as such databases grow it becomes necessary to address the issue of efficient storage management methods. The intention of this project is to examine the requirements for both working memory and backing storage databases within a TMD scenario, and investigate appropriate database management techniques for real-time system performance.

Object-oriented approaches to data representation are receiving some prominence in the development of sizeable AI systems. Such storage actually introduces some complications for data management because of the presence of such things as access-oriented procedure calling and demons, which allow procedures to be *embedded and executed within the database*. Consequently, the project also investigates the issues associated with storage and use of objects.

The work will comprise the following tasks:

(1) Analysis of usage for a representative application and scenario. Takes a prototype, extrapolates on its functionality and produces descriptions and figures on what is being stored, accessed and matched against, what structure such items have, what speed of access is required and what frequency. Creates a model for quantifying parameters associated with database use.

(2) Research on object-oriented databases. Examines research on large object stores, studies complications object-oriented language features add to conventional database models and decides on an approach suitable to requirements elicited above.

(3) Exploiting structure in data. Examines mapping between "larger scale

structure" in application data and efficient storage and retrieval mechanisms. For example caching schemes have been one of the mechanisms exploited by RISC processors to increase performance substantially; TMD applications will be dealing with spatially distributed tracks and doing spatial correlations in data; can data be organised so that a caching mechanism can pre-fetch spatially close track data? What implications does such function-specific structuring have on data that is used for many things in many functions?

(4) Prototyping of a mechanism. Chooses a favourite database structuring and access mechanism, implements on suitable platform, takes a prototype database and produces a demonstrator for a small subset of functions in the prototype. For example, will take part of classification module in the TMD Situation Assessment prototype and modify it for use with the new database system.

Relationship to Programme

Within the three year timescale of the programme it will not be possible to receive input from one of the TMD prototype projects and feed results into another. Input from the development of one of the large TMD prototypes is required, particularly one that is using: a track store, encyclopædic data and an object oriented representation. SP2.2.3.4, on Situation Assessment for TMD, is a good candidate in these respects.

Time and Effort

A budget of three man years over a period of eighteen months is required.

Inputs / Assumptions

The work here requires input from a prototyping project in the TMD area in order to examine in detail the database requirements. Obviously, the broader in scope the prototype the more representative it will be of the ultimate needs. Similarly a scenario, or data on scenarios, will be needed to quantify such things as the number of objects, hypotheses, updates, etc.

Deliverables

- A prototype database management unit for TMD data.
- A model for representing database needs and evaluating the balance between backing storage and main memory given technology status.

Resources

Hardware:	AI Workstation	£25k
Software:	AI Toolkit	£15k
Total:		£40k

Note that it is hard to quantify software needs until the prototype to be used as a host for the study has been identified. It would clearly be beneficial to take code directly from that prototype, and it would therefore be necessary to have the same development environment for this project.

The following skills and experience are central to the success of this project :

- analytical experience of applications requiring the definition of data and data-structural requirements;
- technical appreciation of the implications for system development of different data-structuring decisions;
- knowledge of the operational limits of novel database structures (or ability to formulate appropriate metrics);
- familiarity with different software techniques for coupling database and an inference component in a time-critical system;
- experience of generating and assessing the appropriateness of different architectural solutions to performance improvement eg. whether hardware assists are necessary;
- familiarity with SDI/TMD scenarios.

SP 2.2.3.1 Adaptive Preferential Defence

Description

Adaptive preferential defence refers to the identification of targets and kill potential for incoming tracks, asset evaluation for choosing the extent to which each can be defended and weapon allocation prioritisation.

Objectives

The objectives of this project are to:

(a) Investigate the functional requirements of a knowledge-based system in the resource allocation function required for TMD.

(b) Evaluate the applicability of techniques form naval resource allocation work in the Theater Missile Defence domain.

(c) Design a TMD resource allocation prototype to be hosted on an AI Toolkit.

(d) Explore man-machine interaction possibility within the TMD resource allocation function.

Technical Work Involved

Overview

The key feature of this project is to explore the monitoring and supervisory role of the human operator in this stressful and time constrained environment. The operator will have to quickly assimilate the nature of the threat and initiate the response. This response would not relate to a single threat object but to the initiation and nature of a defensive posture, and the changing priorities or courses of action.

The project calls for study of the real time design aspects required to provide time constrained reasoning, and the supporting HCI necessary to allow operators to exert supervisory control. Many different classes and forms of knowledge will be required to be stored and manipulated relating to temporal and spatial structure of raids and intentions of the aggressor.

Research Components

The project acts as a vehicle for several prominent technology objectives to be explored, as outlined in the components below.

1. Hardware Architectures

The exploitation of parallel architectures for planning tasks has not been explored. This resource allocation project provides an opportunity to study the issues involved in parallel implementation of such constraint satisfaction tasks and contrast relevant paradigms with analysis tasks in data fusion and situation assessment.

The work will not involve prototyping of new algorithms. Instead it will concentrate on identifying characteristics of the domain and the existing Resource Allocation methods that could be exploited or could lead to parallel algorithm development.

2. HCI Component

There are three sub-topics within this component.

(a) To understand how users form models of the system with which they are interacting, and to improve system development methods accordingly. The study will be concerned with analysing users' mental models of computer systems and deriving HCI design guidelines. The user interaction with the prototype will be observed and recorded. This information in conjunction with interview data and analysis of system documentation will be used to construct a model of the user's understanding of the system. The model would then be validated by further experimentation. The information would then be used to make recommendations on improving the HCI to C^2 systems. A review of the relevant User modelling literature would also be undertaken to aid selecting the most appropriate modelling technique.

(b) To examine the factors affecting the representation of uncertainty in predictive displays in knowledge-based C^2 systems. An analysis of the potential requirements for predictive displays in a situation assessment and resource allocation domain will be carried out. Different ways of representing predictions, and particularly uncertainty, will be explored experimentally. Predictive display prototypes capable of displaying behaviours and associated uncertainties will then be constructed. A set of user trials would then be run with the prototypes to identify user preferences. A review of the literature on predictive displays would also be undertaken.

(c) To understand the role of explanation in a highly time constrained component of a knowledge-based C^2 system, and to investigate the design of explanation facilities. The design of the explanation facility of the TDS will be studied and its efficacy to improve user's understanding of the system operation will be assessed. Alternative ways of explaining the same information will be explored. In addition, the format of the explanations will be investigated, in particular the augmentation of explanations by use of graphics and pictorial symbology (ie as opposed to plain textual information).

Within these sub-topics the general HCI aspect of the display of information to include symbology, graphics and interactive techniques will be considered.

3. Knowledge Representation Component.

This component will:

(a) Compare naval and TMD resource allocation problems.

(b) Adapt naval resource allocation representation and planner for TMD domain.

(c) Develop a "progressive reasoning" planner.

(d) Integrate into interactive decision support environment.

There are broad similarities between the naval and TMD resource allocation problems to be studied and exploited, but this will require access to data on potential firing doctrines within TMD. There is expected to be a similar demand from TMD for good representations on uncertainty and temporal information as exists in the naval case; the main area of difference will probably be that there is no dynamic higher level plan that constrains resource allocation, instead there will be a more precisely defined set of rules of engagement.

4. System Design Component.

Designing a progressive reasoning system for planning must take account of the operator's need for interaction and possible intervention in the planning process. In the hierarchical evolution of a plan, the user should not be constrained to making inputs at a single level or just at the level currently being refined by the planner.

While the planning architecture proposed for the project exploits much of the work done on naval resource allocation projects, it will require re-engineering to support progressive refinement and a more constrained capability for operator intervention.

Relationship to Programme

This project is concerned with looking forward to problems that will be encountered in a real-time highly stressed TMD scenario. A new stand alone prototype will be required, not constrained by current implementations, but building up on the knowledge and experience acquired from them.

There is potential for sharing a brought-in scenario with SP2.2.3.1 (see Input and Assumptions).

Time and Effort

The effort for each of the components are:

Hardware Architectures: 2my

HCI Component: 4my

Knowledge Representation Component: 2my

System Design Component: 0.5my

The total effort will be 8.5 man-years over an eighteen month period.

Inputs and Assumptions

It is assumed that experience will be available from the ARE RAP-1 and RRASSL prototypes as well as from any preceding work in the Development Method Prototype (SP2.2.3.4).

The most appropriate scenario is that developed by Hunting Engineering Ltd (HEL) for the SDI UKAS study. This contains trajectory details of each cluster of objects over the period of the raid as seen from each sensor and locations of own collateral and defence units. Alternatively the scenario developed for the RAE/SSL AI Discriminator study could be adapted.

Deliverables

The deliverables from this project will be:

- Reports from each research component giving an analysis and recommendations arising from the component.
- Analysis and recommendations on the value and benefits of the KBS approach to TMD resource allocation.
- A working prototype of the Adaptive Preferential Defence application.
- The knowledge base from the project.

Resources

The following resources will be required over the eighteen month period to support the project:

Hardware:	2 x AI Workstations	£50k
Software:	2 x AI Language	£10k
Total:		£60k

SP 2.2.3.2 Sensor Management

Description

This project is principally about the spatial reasoning and human computer interface necessary in sensor and weapon management.

Objectives

The objective of this project is to build a demonstrator to show HCI and AI techniques working together, in an application which makes use of an appropriate set of spatial representations of the world that are conveyed to the user. Particular research objectives will be to investigate:

(a) The real time design aspects of re-optimising sensor or weapon coverage in a dynamic scenario.

(b) The problems associated with the storage and real-time manipulation of a large amount of spatial information in a KBS.

(c) The problems of representing uncertainty in spatial data.

(d) The problems associated with real-time coupling and interaction of the knowledge base and database.

(e) The real-time display of uncertainty and explanations in a spatial reasoning system.

Technical Work Involved

Overview

The project can be considered under two application aspects although the approach is similar for both. These applications aspects are the coverage and management of sensors and weapons:

a) Sensors

In the Electronic Warfare environment, with the use of jammers and other electronic countermeasures, there is the need to adaptively control the coverage and performance of ground/shipborne radars to achieve optimum coverage of the battle space so that the sensors may support their concept of operation. That is the sensors should be able to achieve an intended contribution to the overall task rather than just achieve some general form of coverage. Added problems to the planning and control of the sensors are:

- sensor assets may be lost/destroyed
- nuclear effects (fireballs and Beta patches) may blind sensors
- allocated frequencies may not be usable

Equally important is the situated exploitation of phenomenology. In the naval scenario this implies radar, visual, IR and EW, and in the TMD scenario this implies radar of various basic types, IR , Ladar (laser radar) and various satellite systems.

Sensor management aspects include positioning of sensors and EMCON policy; sensor mode (surveillance of tracking); beam, dwell and scan parameters; as well as the effects of the environment on the sensor performance. A series of experiments will be developed to investigate sensor management and coverage planning and re-planning. Comparison of results would be based on overall speed of operation and the effectiveness of decisions obtained.

b) Weapons

Good knowledge is required of the instantaneous state of own assets to be defended and of the current weapon coverage and state, including holding, to optimise the coverage to achieve the overall defence objective. The algorithms must consider the number of remaining assets in a defined class, their net value and ability to achieve their objective as well as priority to the allies. The weapon primary coverage area could then be modified and if time allows the firing unit moved. This is equally applicable to SDI and naval applications.

Technical Components

The goals of the project will be achieved by a number of components related to different technologies:

1. Real-Time Systems Design

A critical issue for controlling the sensor and weapon coverage management process is the detection of significant events in the situation data being monitored. In other words, deciding when either sensor or weapon coverage should be altered. Any available scenarios should be studied in order for appropriate heuristics to be developed.

2. Knowledge Representation

As stated above, there is a strong requirement for a robust and rich representation of spatial knowledge. Sensor and weapon coverage envelopes and track predictions all require representation and associated computations (e.g. intersection of RV flightpath and weapon envelope). This is not quite so easy as it sounds, the difficult component being a means of evaluating the shortcomings in coverage, and planning a better one.

The use of jamming will add the requirement for an appropriate representation of uncertainty to be included. Appropriate knowledge representations for the deep modelling of sensors and weapons will also be considered.

3. DB/KB Interaction

The prototype will need to show the use of a geographic database for the spatial reasoning tasks involved in assignment of sensors and weapons. The prototype may also utilise an encyclopaedic database containing models of the sensors and weapons being controlled. Optimising the coupling between any KBS and the databases in

terms of speed and the ability to handle the range of queries required will be necessary.

4. Human Computer Interaction

The potential for officers to participate in or supervise sensor and weapon management needs to be investigated. Difficulties centre around the speed of action and the number of tracks. Research needs to address:

(1) The display of weapon engagement zones (potentially with associated kill probabilities) and sensor coverage.

(2) Display of tracks and threat tubes with uncertainties.

(3) Interactive, cursor-controlled movement and shaping of an engagement zone.

(4) Display of machine generated alternative sensor and weapon deployments.

(5) Mechanisms for selection and manipulation of machine generated deployments.

Relation to Programme

This project provides a well focussed application which will demonstrate the integration of results achieved in each of the technology streams. The sensor and weapon assignment problem has clear parallels with the Naval application domain.

Time and Effort

The effort for the components is:

Real Time Systems Design:	0.5 My
Knowledge Representation:	4 My
DB/KB Interaction:	1 My
Human Computer Interaction:	3 My

The total effort will be 8.5 man-years over a 2 year period.

Inputs and Assumptions

This is a stand alone prototype and does not rely on inputs from other projects to be viable.

There is relevant research in other projects, notably SP2.1.1.1 on DB/KB interface techniques, SP2.1.1.5 on the optimisation of tactical picture displays, SP2.1.2.1 on extending the SAP, SP2.1.3.4 on appropriate techniques for providing explanation facilities, SP2.1.2.4 on HCI for Situation Assessment and Resource Allocation, and SP2.2.2.5 on integrating knowledge representations.

A new scenario will need to be developed for the sensor coverage application, which will not model the threat objects in any detail, but only the general direction and density of threat objects. The main feature of the scenario will be the details of the E.W. threat in sufficient granularity to cause a change of coverage plan.

The scenario for weapon coverage will only be in terms of threat density and need not look beyond cluster details. This would be sufficient to exercise the weapon coverage process. Any knowledge required will be provided by the contractor's experts.

Deliverables

The deliverables from this project will be:

(a) Definition of the problem to be addressed, first specification of prototype system, including paper knowledge base.

(b) Analysis of contribution of each technology component to the proposed prototype.

(c) Software prototype, with supporting documentation.

(d) Results of informal evaluation of functionality and HCI by prospective users.

(e) The knowledge base from the project.

Resources

The following resources will be required over a two year period to support the applications program:

Hardware:	3 x AI Workstation	£75k
Software:	3 x AI Language	£15k
Total:		£90k

The following skills and experience are central to the success of this project :

- awareness of the contribution hardware and software components make to the overall sensor system;
- experience of different event-detection strategies in an applications context;
- experience of modelling complex, information-passing systems;
- experience of novel database structures and of coupling a database to a knowledge-based component to meet performance requirements;
- experience of systems that involved representing track and engagement zones in a highly interactive environment;
- well-established industrial/military reputation for KBS research;

- experience of SDI/TMD work and scenarios;
- skill at the construction of large-scale KBS prototypes.

SP 2.2.3.3 Intention Prediction of Intelligently Manoeuvering Objects

Description

The aim of the project is to develop a method of predicting possible future paths of intelligently manoeuvering objects by incorporating knowledge of object manoeuvre characteristics into algorithmic schemes for track prediction.

Objective

A significant component of the situation assessment process, or threat assessment as it may be termed, is the prediction of impact points for warheads based on data on current trajectory and object characteristics. This project is concerned with studying and experimenting with methods of adding knowledge of the manoeuvre characteristics of objects to algorithmic tracking systems that are based on ballistic data and track histories. The objectives of the project are to investigate :

(a) How to cope with uncertainty in object identification data or object models, and the variability of manoeuvre capability.

(b) How to maintain alternative "future world" perspectives, and do so in real time.

(c) How to display uncertain predictions in a meaningful and useful way to operators.

Technical Work Involved

Overview

Much work has been done on the development of algorithmic methods of track prediction for manoeuvering objects, in applications such as Air Traffic Control. These methods, for example those based on Kalman Filters, contain no explicit domain knowledge and may even contain the assumption that the tracked objects are being co-operative.

The algorithmic methods will, on their own, be inappropriate to the TMD application because of the RV's manoeuvre capability and the disruption to tracking that this could cause. The research proposed below is based on supporting the algorithm with knowledge of the manoeuvre capabilities of RVs and penaids, so that corrections can be made to tracking processes and predictions of impact points. Since different RVs will have different capabilities, uncertainty of object identities in the tracking data will be a major source of difficulty in applying the knowledge and is therefore a subject of research.

The possibility of working from expectations of likely targets back to predictions for tracks is also to be explored.

Research Components

1. Knowledge Representation and Manipulation

The identification of good candidate tracking algorithms for augmentation with knowledge bases; development of a method of embedding the algorithmic processing into a knowledge-based control scheme (e.g. rule or frame based).

Development of a framework (including a scenario generation capability) in which to build knowledge-based enhancements to the chosen algorithm. This should allow both data-driven reasoning from object classification data, and backward chaining from prediction of likely targets. It should support the maintenance of multiple prediction hypotheses in real-time.

2. Knowledge Representation and Manipulation

Study of representation needs for describing manoeuvre capabilities of RVs and uncertain predictions that involve them. Appropriate storage for these, along with target data, and mechanisms for real-time access need to be defined.

Incorporation of experimental object models into a demonstration system utilising the framework (above).

3. HCI

Development of HCI for the prototype that is able to display the inherent uncertainty in the predictions and maintain a real-time picture of them. Since operators will be unavailable to assess this interface, it will be developed with reference to theoretical work and experimental evaluation and refinement.

Relationship to Programme

This project tackles in detail an aspect of situation assessment that is considered by projects such as SP2.1.2.1, the Enhanced Situation Assessment Prototype, and SP3.1.1.2, Co-Operative Planning Systems for Command and Control, on the naval side, and for TMD, the incorporation of tactical situation processing from the TMD Development Methods Prototype (SP2.2.3.4). There, quite simple predictions of enemy intentions will be utilised in predicting possible future states of the scenario. Here, specific algorithms and heuristics will be developed on which to base those predictions.

Time and Effort

The project will consume seven man years of effort over a two year period at a cost of £560k. This effort is distributed as:

HCI	2 My
Knowledge Representation	4 My
Databases	1 My
Total	7 My over 2 years

Inputs / Assumptions

The project is not dependent on input from any others within this programme, or from the RAE/SSL AI Discriminator Programme. The project has therefore been made independent of the timescales of these research programmes. It is assumed that, rather than embody highly classified data on orange Re-Entry Vehicle and penaid capabilities, types of potential manoeuvre will be incorporated into non-specific object models for the system to work with. Such information should be made available through the SDIPO, but the project contractor will be required to supply the experts who will understand the relevance of this information. A simple scenario will be generated within the project using the supplied characteristics. A full raid of threat objects is not required to exercise the prototype.

Deliverables

The deliverables from this project will be:

(a) A review of methods for track prediction using combined heuristic and algorithmic methods.

(b) A prototype of the intention predictor performing on scenario-derived data

(c) A description of constraints on incorporating the method into other demonstrators.

(d) The knowledge base developed in the project.

Resources

Resources will be required over a 2 year period, so the following items should be purchased and committed to the project:

Hardware:	AI Workstation	£25k
Software:	AI Toolkit	£15k
Total:		£40k

SP 2.2.3.4 Development Methods Prototype

Description

The aim of the project is to provide a research platform to support development methods projects whilst investigating further issues in Situation Assessment that will extend from those related to the near term naval and TMD KBS projects.

Objectives

The objectives of the project are two-fold. The main objective of the project is to provide a focussed applications prototype to provide a platform for the investigation of techniques for the specification and evaluation of KBS outlined in the following projects:

SP2.2.2.1 Specification of KBS

SP2.2.2.2 Verification and Validation of 'Safety Critical' KBS

SP2.2.2.3 Robustness of KBS Architectures

SP2.2.2.4 Operational Adaptivity of knowledge bases

The particular applications oriented objectives of the project will be to:

(a) select and explore new topics for research into situation assessment which relate to TMD and are not already covered by existing work in RAE/SSL.

(b) build up from the experience gained in the TDP.

Technical Work Involved

Overview

The first activity in this project will be to select the applications topics for research. Examples of tactical situation assessment which are potential applications for inclusion in this project are [Miles, 1988]:

(a) Threat Assessment

(b) Defence Assessment

(c) Mission Assessment

(d) Outcome of Actions

(e) Weapon System Geometrics

(f) Rules of Engagement / Course of Action

(g) Sensor and Weapon Coverage and Status

(h) Plan Monitoring

(i) Surveillance Estimates

These applications have a synergy between the naval and TMD domains. However, it is proposed that a TMD application is selected.

It is anticipated that as a result of the TDP the researchers will have an understanding of how the output of the SAP is assimilated and this will form the basis of a further set of rules to be incorporated in an enhanced functionality prototype.

It is suggested that the most suitable topic for this further research is to investigate reactive (dynamic) situation assessment, and in particular to investigate the real-time selection of Course of Action and to modify such a selection as a result of raid analysis.

Research Components

This project breaks down into a number of work packages. These are:

(a) Selection of suitable topics in situation assessment for research. The suggested topics relate to the real-time selection of Course of Action.

Once the topics are selected, work will begin on the development of the prototype system. In the course of the development cycle the project will provide the vehicle for the investigation of appropriate techniques for the specification and validation of the final system. Controlled experiments will be carried out to explore options and evaluate alternative approaches in accordance with the descriptions for projects SP2.2.2.1 to SP2.2.2.4 (inc).

(b) Selection, procurement and setting to work of the hardware and system software for the prototype.

(c) A requirement specification for the application will be produced in accordance with the method defined in the development methods program.

(d) Elicitation of the knowledge for the knowledge base. Techniques will be explored for monitoring and controlling the knowledge elicitation process as an element of the KB validation process.

(e) Implementation of the selected situation assessment applications.

(f) Testing and bench marking the system.

(g) Evaluation and reporting on the specification and validation techniques developed in the course of the methods project.

Relationship to Programme

This prototype is a stand alone system that will not directly evolve from the preceding program. However it is envisaged that wisdom gained by the TDP and in the RAE/SSL programme will be used in the formulation of this project. There is potential for sharing a brought-in scenario with SP2.2.3.1 (see Input and Assumptions).

The prototype developed in this project, and the outcome of the enhanced ARE SAP, will be used to support the Sensor Management project SP2.2.3.2.

Time and Effort

The effort within each work package is:

Selection of research topics	3mm	
Generation of requirement spec.	0	(covered in SP2.2.2.1)
Procurement and STW of system	3mm	
Knowledge elicitation	0	(covered in SP2.2.2.1)
Application implementation	2my	
Testing and Benchmarking	1.5my	

The total effort will be 4 man-years over a two year period.

Input and Assumptions

The research topics identified in the first work package will be agreed between ARE and the contractor before proceeding.

Information for the knowledge base will be elicited by experts from the contractor's team in accordance with the formal method. The contractor will supply the experts.

The most appropriate scenario is that developed by Hunting Engineering Ltd (HEL) for the SDI UKAS study. This contains trajectory details of each cluster of objects over the period of the raid as seen from each sensor. Alternatively the scenario developed for the RAE/SSL AI Discriminator study could be adapted.

Deliverables

The deliverables from this project will be:

- The development methods prototype running the Situation Assessment applications.
- The knowledge base from the project.
- Analysis and recommendations arising out of the studies in projects SP2.2.2.1

to SP2.2.2.4. These will be the recommendations on techniques for Specification and Validation of KBS and prototyping tools to support validation methods.

- Analysis and recommendations on the value and benefits of the KBS approach to the application.

Resources

The following resources will be required over a two year period to support the applications program:

Hardware:	1 x AI Workstation	£25k
Support software	1 x AI Language	£5k

Additional hardware and software will be required to support the development methods projects and are identified with those projects.

The following skills and experience are central to the success of this project :

- a high-level overview of the other parts of the programme;
- a technical appreciation of how the other parts of the programme have been implemented;
- a senior and expereienced person with a clear view of the role of different techniques within the life-cycle model;
- software implementation management skills to deal with the integration of complex components;
- experience in building KBS development methods prototypes in the aerospace field;
- staff with SDI/TMD experience.

SP 2.2.3.5 Hybrid Approach to Data Fusion

Description

This project is concerned with the integration of KBS/Symbolic and algorithmic/numeric processing components with respect to the data fusion scenario of the TMD application.

Objectives

- comparison of knowledge-based and algorithmic approaches to association, correlation, discrimination and prediction with reference to performance and constraints on use;
- identification of ideal hybrid approach, with estimates of likely improvements in performance (speed, accuracy), reliability (fault tolerance, survivability to loss of sensor) and scalability over purely numeric or symbolic approach;
- examination, through prototyping and benchmarking of performance, of functional capability of hybrid approach;
- consideration of hardware requirement of hybrid approach with a view to real-time performance.

Technical Work Involved

Neither a wholly symbolic, nor a wholly numeric paradigm will be capable of solving completely all of the problems associated with data fusion in a large scale, complex real-world application such as TMD. The overall goal of this research is therefore to determine the most promising paradigms for integrating symbolic and numeric techniques of data fusion, and to evaluate their likely performance in comparison to a fully AI based solution

The research will comprise the following :

- review of quantitative and qualitative methods of data fusion to identify those relevant to TMD, e.g. multiple hypothesis tracking, joint probabilistic data association, and variable dimension probabilistic data association;
- development of appropriate consistency tests which must be applied to the various data to determine if they relate to the same physical entity. This is most commonly achieved through the use of statistical hypothesis tests, where the null hypothesis is that the data are consistent. The basis for evaluating the null hypothesis could be 'similarity' (e.g. confidence of matching), 'distance' (e.g. Euclidean), 'likelihood' (e.g. chi-squared test), or other measures derived from the error model;
- development of appropriate methods for combining the data, e.g. maximum likelihood, minimum error, extended Kalman filtering, fuzzy logic, or Dempster-Shafer theory of evidence. More specifically, Kalman filtering is one of a number of techniques developed in the field of control, and has been successfully applied to the fusion of low-level geometric primitives which have

well defined associated error characteristics. Since the Kalman filter requires affine subspaces (points, lines, planes), it is difficult to apply to the fusion of symbolic information such as 'these objects are hostile', for which Bayesian techniques might be more applicable. A key issue here is the representation of uncertainty;

- investigation of appropriate qualitative methods of controlling the quantitative techniques, and of integrating them successfully with existing symbolic data fusion paradigms. This can be done by building detailed models of both sensors and algorithms which incorporate 'deep' knowledge of such things as sensor physics, and algorithm performance, or by describing sensor data, at a low level, using symbols and qualities alone, and then employing either belief-network or confluence methods to reason about the consequences of this data on different interpretations of the environment;
- development of a prototype hybrid system based on selected techniques and application to TMD application scenarios, including evaluation of performance improvements and identification of outstanding research problems;
- study the hardware architectural implications of the methods developed above and in particular the balance required between centralised processing and control, and decentralised/distributed alternatives; the requirements for real-time performance of the method will be identified;

Relationship to programme

Time and Effort

Hardware Architectures :	5 my
Total :	5 man-years over 3 years

Inputs / Assumptions

This project will need TMD scenarios, either generated by SP4.1.1.2, or from a source such as RAE.

Deliverables

- Analysis of suitable components for a hybrid data fusion system.
- Prototype hybrid data fusion system.
- Analysis of results from performance evaluation.
- Proposals for real-time realisation of the method.

Resources

Hardware:	AI Workstation	£25k
	Numeric Workstation	£20k
Software:	AI Toolkit	£15k
Total:		£60k

Access to SDIO studies relating to algorithmic methods is required.

The following skills and experience are central to the success of this project :

- appreciation of the possible contribution of symbolic or numeric components to C^2 systems eg. TMD;
- experience of implementing and integrating a variety of different techniques (eg. representational schemes or logics) on a single platform;
- an architectural understanding of different techniques (and their combination) in order to guide the choice of appropriate hardware paths;
- staff with experience of SDI/TMD work.

SP 3.1.1.1 Distributed Situation Assessment

Description:

The investigation of distributed problem solving systems and their application to Situation Assessment for Naval or TMD domains.

Objectives

The objective of the project is to examine the application of DAI to Situation Assessment as a means of controlling the combinatorial Data Fusion problem and responding to the natural task breakdown and constraints of operational Naval and TMD architectures.

Issues to be addressed by experiments in this project include:

- Convergence - how is a single picture assembled by passing around partial pictures;
- Operational Structures - how do service-defined structures define information availability and flows;
- Network Architectures - what constraints are imposed by physical structures, and the mobility of platforms;
- Robustness - how can systems be made immune, or insensitive, to communication problems (i.e. loss of links or nodes);
- Resources - how can or should information about other nodes in a problem-solving network be used to influence its behaviour.

Technical Work Involved

Overview:

The work programme draws on domain studies of Naval and TMD command and control systems to investigate the following aspects of distributed problem solving:

Convergence:

If distributed nodes are generating individual tactical pictures and passing them to other nodes while receiving pictures from them, the issue of convergence of these pictures to an agreed view needs addressing. In part this requires examining whether individual ships in a task force actually do share the Flag's picture or hold slightly differing views themselves.

Operational Structures:

There are pre-existing Naval command structures on each ship and operating across a task force as a whole. (The working assumption is that these will not change markedly with the introduction of KBS.) This pre-defines what information should be available where and provides a framework for experiments to be designed.

For TMD there are defined architectures for the decision making hierarchy that are themselves part of a larger command and control network. Again this both serves to define and constrain the nature of information flows.

Network Architectures:

Operational structures define a functional architecture; the hardware defines a physical one. The hardware imparts limitations on bandwidths, communication routes and such things as failure rates and data losses. The implications of these on the ability to perform the required functions needs to be assessed.

Since there is mobility in the sensor platform, the fields of view of sensors may change. The implications of this on picture compilation methods also requires study.

Robustness:

Drawing on potential failures in communications due to physical constraints in the domain, methods of achieving robust performance need to be addressed. Robustness issues also stem from other limitations, such as the accuracy of information being communicated and its topicality. Transcripts from exercises indicate that officers on ships are making explicit decisions about what to communicate and when, and the specific quality of the information that is being communicated. This judgement of quality is shown to vary between individual officers; recipients of the data are also aware of these differences and their implications. The timeliness of communicated information also varies from source to source and from time to time, with delays of several minutes being typical, and on occasion reports being up to fifteen minutes late.

Resources:

Within a physical architecture, different nodes may have different capabilities and qualities. The degree to which a node can or should know the capabilities and goals of the others it interacts with, and/or share its goals, and the effects of such factors on performance are all subjects for investigation.

Research Components:

1. Distributed-AI

Development of the experimental environment for scenario generation based on the RAND *Message Puzzle Task.* Implementation of basic situation assessment rulebases for processing same.

The experimental element is based around a fabricated domain to simplify investigation of the issues outside of the constraints imposed by a large and cumbersome demonstrator (such as TDS or TDS + SAP). This small domain allows scenarios to be rapidly changed along with analysis processes. In providing a flexible experiment environment it allows the differing constraints found in Naval and TMD domains to be analysed and contrasted. For convenience, a starting point would be the example architecture proposed by Wesson and Hayes-Roth ("Network Structures for Distributed Situation Assessment", RAND report no R-2560-ARPA).

2. Distributed-AI

Investigation of information distribution structures in Naval and TMD architectures.

This involves assessing existing communication structures within the two domains and the reliability of information transfer amongst nodes. Experiments will be conducted on the prototype to assess the performance implications of various architectures and their response to communication problems, that is the robustness of their inferencing.

3. Hardware Architectures

Assessment of timeliness of information flow in Naval structures and experiments.

In the Naval case there is clear evidence of problems in receiving timely information from remote ships. This component is intended to scale the problems involved and investigate their impact on the prototype system through experimentation, and development of a reasoning strategy that can cope with the problem.

4. Human Computer Interaction

To investigate aspects of team structure and task partitioning within Naval operational environments, particularly between ships.

Related to the second component, this part is concerned with co-operative behaviour between the various individuals involved in the Situation Assessment process and the communication that occurs between them outside of message transfer in electronic systems. This information needs to be incorporated into the architecture experiments being conducted in the second component.

Relation to Programme:

The intention with this project is to make it independent of the main programme and to gain further insights into Situation Assessment by approaching from another angle. This alternative perspective will ultimately feed in to the mainstream research.

While aspects of task analysis proposed under the HCI heading above may be covered in SP2.1.1.4, it is unlikely that that project will address functional distribution issues in sufficient depth for the purposes of the experiments here.

Time/Effort:

Distributed AI:	3.75 My
Human Computer Interaction:	1 My
Hardware Architectures:	0.25 My
Total:	5 man years over 2 years

Since this programme is composed of some independent parts it could be funded in stages.

Inputs and Assumptions:

As the experimental programme is based on a fictional domain there is no dependence on the completion of other development projects. Similarly, domain experts will not be needed.

The project assumes the availability of data on information distribution in both Naval and TMD domains and access to appropriate exercise data. Much of this data is known to already be in existence but it will need tracing.

Deliverables:

- recommendation for applying DAI techniques to the TDS and TMD demonstrators
- report, based on analyses of exercise transcripts and observations, on the way human organisations approach the distributed task.
- demonstrators for the experimental domain

Resources:

Experimentation would be best conducted with an appropriate development tool for DAI systems, of which there are several under development. The availability of such tools will shorten development timescales considerably. The cost of such a package is expected to be around £25k, thus

Hardware:	AI Workstation	£25k
Software:	DAI Toolkit	£25k
Total:		£50k

The AI workstation should already be available at any contractor's site (where all the work can take place). A DAI toolkit may or may not need to be purchased by the contractor for delivery under the project to ARE depending on availability conditions applying to such a package.

The following skills and experience are central to the success of this project :

- experience in the theoretical analysis of complex multi-component representations;
- experience at implementing at least proof-of-concept, multi-platform AI systems;
- staff with a good familiarity with distriubtuted Naval command structures and process;
- analytical skill at complex decision-making and Distributed AI.

SP 3.1.1.2 Co-operative Planning Aids for Command and Control

Description

Investigate the issues involved in building interactive decision support systems for resource allocation and planning (RA&P) functions.

Objectives

The issues to be addressed in this experiment are:

(1) The means by which a system can record and disseminate a plan, and the rationale behind it, to all the officers who will use it.

(2) The role of KBS in simulating possible "future worlds" based on expectations of enemy actions and reactions to proposed plans.

(3) The potential roles for KBS in Resource Allocation and Planning - such as critiquing and planning per se.

Technical Work Involved

Overview

The aim of this project is to take account of limitations found in command and control planning processes, as revealed in documents describing observations of control rooms and the command process during exercises. These issues can be summarised as:

1. Recording and remembering all the pros and cons behind a plan.

2. Exhaustively considering all possible courses of action.

3. Avoiding premature decisions on plans.

4. Disseminating the rationale behind plans.

To achieve this, an interactive planning aid is proposed that will form a workstation for those involved in the planning process. During planning sessions it would, for example, be driven by the Staff Operations Officer while the rest of the planning team view the screen (or screens), in much the same way as a planning table is used currently. Having captured a plan within the system it can then serve as a means for dissemination to, say, the various warfare officers.

The intention is to produce two prototypes - the first based largely on HCI technology and appropriate representations where the users are doing all planning, but the system records, simulates and disseminates; the second where the system is capable of generating plans itself and these are presented as options to users and may be manipulated by them.

Research Components

The technical work required to support the development of such a system will be primarily in the areas of Human Computer Interaction and Knowledge Representation and Manipulation. These are separated into two components below, though there is considerable interaction between all the sub-components.

1. Human Computer Interaction

The HCI investigation needs to cover the following (note that all of these will lead to features within the prototype HCI system for the demonstrator):

- User Requirements Elicitation - establishing the operational structure into which the system will fit and identification of the system's role within it.
- KBS in HCI - developing mechanisms for the transfer of goals, plans and world knowledge between man and machine.
- Explanations - developing techniques for explaining plans and their rationale as part of the briefing an plan review process.
- Display Management - investigate the generation and use of overlays and situation predictions in support of the planning process.

2. Knowledge Representation and Manipulation

The knowledge representation issues tackled during prototype development will include:

- Representation Languages - investigation of requirements and development of structures for plans, counterplans, goals, intentions and their supporting material.
- Multiple Worlds - controlled generation of multiple hypotheses for future situations based on knowledge of enemy intentions, own-force plans and likely enemy responses.
- Generating and Understanding Plans - development of systems for recognition and generation of plans, goals and intentions incorporating temporal and spatial information.
- Critiquing - development of methods for applying knowledge to critiquing of user plans, the use of plans during resource allocation and analysis of the currency of plans given the evolving scenario.

Relation to Programme

While largely independent of other experiments, this project will be a major driver for advanced HCI and Knowledge Representation research. Study components relating to Naval practice will have features in common with those in SP3.1.1.1 where co-operative Situation Assessment in being studied.

Clearly there is a link to other work on resource allocation taking place in both TMD and Naval research projects. For example, SP2.1.1.6 "Operator Interaction with C^2 Systems", SP2.1.2.2 "Enhanced Resource Allocation Prototype". In the latter case, that prototype would be expected to incorporate a plan of the kind being developed here.

Time and Effort

Human Computer Interaction:	2 My
Knowledge Representation:	3.5My
Total:	5.5 man years over 2 years

Inputs/Assumptions

Access to exercise data will be essential. It would be highly beneficial to observe an exercise at first hand, either at HMS Dryad or elsewhere, and have access to various officers; neither of these is essential, merely preferable.

The required prototypes are not dependent on the TDP and require quite separate scenario support. Since plans are being generated and acted upon it is important for the planning systems to be able to "watch" an evolving scenario in which own-forces can be tasked and the opponent responds to the plans that have been enacted. This support can be provided by an object-oriented simulation environment, but appropriate simulators may already exist at ARE or elsewhere. It will be valuable to evaluate existing simulation systems at ARE to determine their suitability for this type of use within an on-line system.

Deliverables

- user-driven plan generation prototype
- automated plan generation prototype
- Knowledge bases for the above

Resources

Hardware:	AI Workstation	£25k
Software:	AI Toolkit	£15k
Total:		£40k

An AI Toolkit running on the chosen hardware base will be required. One supporting "multiple worlds" reasoning would clearly be advantageous (approximate cost £15k).

These hardware and software resources should already be available at any appropriate contractor's site. It is not expected that ARE will need to purchase them; this work can be done at the contractor's site.

The following skills and experience are central to the success of this project :

- analysis and implementation experience of complex hypothetical-reasoning applications;
- if available, specific experience of representation and manipulation of alternative plans in a non-academic applications context;
- centre of excellence in the generation , selection and modfication of plans for scheduling;
- HCI skills in the specialised area of co-operative working.

SP 3.1.2.1 The Application Of Neural Networks to Data Fusion

Description

To study alternative inherently parallel knowledge representation models, specifically Neural Networks, in order to discover whether it is feasible to map the data fusion domain onto these models.

Objectives

The objective of this project is the conclusion and extension of work on the application of neural nets to data fusion being conducted for ARE by Aberdeen University.

Technical Work Involved

This work to include:

- The completion of the Neural Network track classification system and its evaluation in relation to more conventional statistical track classification methods.
- Extension of the Neural network system to include wider issues such as the correlation between dissimilar data.
- Completion of the mapping of the Neural Network development system and the neural networks it generates onto a parallel hardware platform, such as a transputer array or the Rekursiv object-oriented machine.

Relation to Programme

The work is based on an independent subset of the data fusion system and therefore there is no required interaction with other projects within the programme.

Time and Effort

A budget of three man years has been allocated to the project. It is assumed that this will be placed at a University.

Inputs and Assumptions

None.

Deliverables

- Prototype of the neural net learning system.

Resources

Hardware:	AI Workstation	£25k
Software:	AI Toolkit	£15k

Total: £40k

These hardware and software resources should already be available at any appropriate contractor's site. It is not expected that ARE will need to purchase them; this work can be done at the contractor's site.

The following skills and experience are central to the success of this project :

- awareness of the application domain so that the evaluation of Neural Networks against conventional track classification techniques can be realistic
- understanding of the area brought from the application of Neural Networks to a number of problem areas
- it may be advisable to have a non-academic perspective on the applicability of this technology to the domain, and to ensure tight adherence to the terms of reference

SP 3.1.2.2 The Application of Machine Learning to Data Fusion

Description

To apply the process of Machine Learning initially to a Data Fusion Knowledge Base and thereby seek to improve its efficiency, refine its rule base and enhance its ability to acquire new kinds of knowledge.

Objectives

Programme objectives are:

- Demonstration of machine learning applied to data fusion rules.
- Understanding of scope of applicability of machine learning within command and control systems.

Technical Work Involved

The project has been included to cover research work already proposed by ARE for which we do not have full documentation.

The work programme will include:

- Identification of performance measures and instrumentation for data fusion system, and of suitable Machine Learning tool and application methodology.
- Development of machine learning framework for learning data fusion rules and/or rule enhancements.
- Generation of exemplary scenarios.
- Experiments to enhance the system's capability by acquiring new kinds of knowledge (e.g. patterns of enemy behaviour).

Relation to Programme

As far as possible this should use existing scenarios and be based around the data fusion subset to retain independence of other projects. This will simplify the letting of the project to a University should this be the aim.

Time and Effort

A budget of three man years effort has been allocated to the project. This could be performed as a University research project.

Inputs and Assumptions

For learning to be demonstrated, several scenarios will be required for training and testing the system. While a component of the work programme addresses scenario generation this is intended to cover only conversion of existing scenario data to a form appropriate to the project prototype. There is therefore a dependency on the scenario

generation component of the main Technology Demonstrator Programme activities.

Deliverables

- Prototype learning system.

Resources

Hardware:	AI Workstation	£25k
Software:	AI Toolkit	£15k
Total:		£40k

These hardware and software resources should already be available at any appropriate contractor's site. It is not expected that ARE will need to purchase them; this work can be done at the contractor's site.

The following skills and experience are central to the success of this project :

- a deep understanding of the exploratory use of Machine Learning techniques
- some commercial input to ensure tight adherence to original terms of reference and offer a different perspective

SP 3.1.2.3 Application of Formal Methods in the Development of KBS

Description

Formally provable descriptions for conventional software have been the subject of research for some time. This project is to investigate the usefulness of the techniques developed in the KBS development process.

Objectives

- To conclude the assessment of the applicability of techniques for converting formal representations of software into executable code and to assess the practicality of using them;
- to discover methods for generating appropriate strategies for testing a KBS from a formal representation of its knowledge base;
- to assess the level of coverage and rigour of mathematical proof required in developing a KBS, given the complexity of these techniques and the availability of software tool support;
- to develop a preferred approach to the application of existing formal development methods to the development of real-time blackboard KBS;
- to develop a notation and associated proof methods for the specification, development and validation of real-time blackboard KBS.

Technical Work Involved

This project is a place-marker within the SANDERLING Project list to cover work currently being conducted by John Haugh.

Relation to Programme

The work is based on a well-defined subset of the Data Fusion ruleset and therefore can be considered fully independent of other projects.

Time and Effort

A provision has been made for four man years of effort. This assumes three man years of intra-mural effort and a one year project, potentially at a University.

Inputs and Assumptions

None.

Deliverables

The main deliverables will be reports covering each objective and demonstrations when applicable.

Resources

Access will be required to a suitable formal specification language interpreter or compiler. Since work is already underway at ARE it is assumed that this is already available and no provision is therefore made for software costs.

The following skills and experience are central to the success of this project :

- a centre of excellence in the Formal Methods field, rather than one person

- a commercial perspective on the applicability of the techniques is likely to prove helpful

SP 3.1.2.4 Intelligent Training Facilities for C^2 Systems

Description

Concerns the use of KBS in Intelligent Computer Aided Instruction (ICAI) for users of C^2 systems.

Objectives

Using the TDS as a vehicle for further research, the objectives for the project are:

- Identify the scope for intelligent interactive training and refreshment of TDS operators.
- Demonstrate the applicability of intelligent training on a subset of TDS functions.
- Assess the advantages of such training methods over conventional tutelage.

Technical Work Involved

Even in its current, partial form, the TDS presents a considerable challenge to any prospective new user. There is a real need for there to be a well-established and efficient method for training new users to ensure that they are able to interact with C^2 systems as quickly as possible. Conventional methods such as manuals, lectures and limited hands-on experience are addressed elsewhere in this programme (2.1.1.7). However, with the wide range of tasks and scenarios which may confront the prospective user, a limited set of training exercises may well be inadequate. Furthermore, once in situ, there is no recourse to large amounts of physical training material on board ship. The provision of an on-line training facility is therefore desirable for a number of reasons: first in the case of personnel needing to be redistributed while the ship is at sea, second to enable easy access to revision material, third to increase the cost effectiveness of the training programme, and finally to expand the range of scenarios which can be presented to inform (and subsequently test) the user. Furthermore, if this embedded facility can be made "intelligent" it can evaluate and respond to the specific needs of a user requiring training in some form. The evaluation would be an on-going process, resulting from the users' performance in specific training exercises, and in actual system use. Again, experience from conducting work based on the TDS will have direct impact on similar provisions for the TMD application.

The work will aim to build and evaluate a prototype intelligent training facility for use with a chosen module of the TDS.

The work will consist of five main activities:

a) Undertake (if not already available) an analysis of the TDS system to determine the tasks for which users need to be trained. The sequencing of training topics, the HCI dialogue management comprising the training courses, and the different levels of user/training will be considered. A series of interviews would need to be held with potential users, and Naval commanders to get their views on the provision of future training needs for C^2 systems.

b) Development of a set of users' learning models and appropriate instructional strategies for one particular module of the Version 1 TDS.

c) Design and production of a prototype intelligent training facility based on the results of (b). This prototype should be able to interface to the TDS system being used for training but can be implemented with an available expert system tool.

d) Experimental trialling and modification of the prototype in a classroom setting.

e) Investigation of the potential for embedding the prototype trainer within the full TDS Version 4, with practical implementation if feasible.

Relation to Programme

This project concerns research around the training issue and uses the TDS as a testbed. On the assumption that the module chosen is functionally equivalent in Versions 1 and 4 of the TDS, prototyping can be based on the former but be used experimentally in training operators on the latter. Where the compatibility assumption holds for other modules, intelligent training facilities can be extended to cover them.

Time and Effort

Human Computer Interaction - 4 my

Total - 4 man years over a 1.5 year period.

Inputs/Assumptions

The main inputs to this project would be work to date on the TDS including access to the code of the chosen module and the capability to run it. SP2.1.1.4 on task analysis and SP2.1.1.6 on operator interaction will also provide complementary input to this project. SP2.1.1.7 on the general provision of training facilities will obviously have close links with this work.

Deliverables

- Software implementing a prototype trainer for a module of the TDS.
- Results of experimentation with the prototype trainer. Recommendations for future intelligent training facilities.

Resources

Hardware:	Workstation	£25k
Software:	Compiler	£5k
Total:		£30k

While the contractor should have a workstation available, the prototyping tool may need to be purchased on the project as a deliverable to ARE.

SP 3.1.2.5 Genetic Algorithms for C² Applications

Description

This project aims to investigate the applicability of genetic algorithms to the tasks of data fusion, situation assessment, resource allocation and planning.

Objectives

This investigation of the applicability of Genetic Algorithms (GAs) must address the following issues:

- Identification of criteria for assessing applicability of GAs.
- Identification of candidate TMD or Naval application areas.
- Elucidation of optimisation criterion for a candidate application.
- Demonstration of GA on candidate problem.

Technical Work Involved

Genetic algorithms represent a specialisation of the more general area of stochastic optimisation. There are a range of applications for stochastic optimisation to possibly play a role within the C^2 task, for example the optimum combination of observations to produce a single result in track association and correlation, finding the minimum risk allocation of defence resources, performing situation assessment on incomplete data. The use of stochastic optimisation is primarily reserved for those problems which are technically designated as NP (Non-Deterministic Polynomial) hard, i.e. they offer one way of trying to solve the combinatorial explosion.

The work will aim to construct software implementations of genetic algorithms solving sub-tasks from the C^2 problem, based on the advantages of using these techniques over those currently in use.

The work would consist of four main activities:

a) To elucidate the sub-tasks most usefully represented as optimisation tasks appropriate for a genetic algorithm approach, with particular regard to NP-completeness.

b) To research and develop genetic algorithms appropriate for application to these sub-tasks, by developing techniques for mapping NP-hard problems onto a genetic algorithm based solution methodology. To show the genetic algorithms applied to representative (real) data.

c) To develop metrics for the evaluation of the effectiveness of genetic algorithm techniquess, especially in comparison to conventional methods, and thereby demonstrate any improvements in performance.

d) To develop metrics for the evaluation of the effectiveness of architectures for implementing genetic algorithm techniques in real-time,

Relation to Programme

This project would use the problem descriptions given in the specification of the TDS (Ref Miles89), together with the existing implementations of the TDS and SAP. Any results would be used as input to the appropriate modules as part of future C^2 systems.

Time and Effort

Hardware Architectures :	3 My
Total :	3 man years over a 3 year period.

Inputs/Assumptions

The main inputs to this project would be descriptions of work to date on the TDS Version 1 and SAP, and would also draw on the results of SP1.1.1 for use in the evaluation phase. The nature of this project is fairly academic and speculative in nature, and therefore extra-mural funding of the work at an academic institution should be considered.

Deliverables

- Analysis of the viability of applying genetic algorithms to sub-tasks within the C^2 domain. Recommendations on those sub-tasks which will serve as possible exemplars for the use of genetic algorithms.
- Software implementations in prototype form of a genetic algorithms on those sub-tasks targetted in the report.
- Metrics, together with any software required for their implementation, to evaluate the effectiveness of genetic algorithms as compared with other techniques.
- Recommendations for architectures to implement any successful genetic algorithms in real-time

Resources

Hardware:	AI Workstation	£25k
Software:	AI Language	£5k
Total:		£30k

SP 3.1.2.6 Machine Learning of Temporal Patterns for Command and Control

Description

Experiments to examine the relevance of work on the learning of 'serial structures' (Grammars) to problems in Theatre Missile Defence and Naval command and control.

Objectives

- To examine the relevance of temporal structure in the classification of objects.
- To examine the representation of temporal structures using a grammar.
- To examine the capacity for plans to be generated from a grammar.
- To investigate the applicability of certain learning mechanisms to the acquisition of a grammar.
- To study the parsing of strings using a learned grammar, use of the parse tree and string generation from a grammar.

Technical Work Involved

Certain aspects of Situation Assessment rely on an analysis of sequences of events or states related to objects or collections of objects in a scenario. A simple example is the identification of emitter classes according to patterns of changes in emitter characteristics; another case would be a sequence of manoeuvers associated with weapon release or characteristic behaviour patterns of an RV or Penaid. Such patterns can be represented using strings of descriptor terms, with allowable strings constrained by a grammar.

Finite State Automata implement parsers or generators for simple grammars. Finite Stochastic Automata parse or generate under uncertainty. Stochastic grammars can be learnt by training on input patterns in a manner similar to Neural Networks.

The technical work on this project thus concerns the marriage of an existing technological capability with a domain problem. The potential exists to learn to recognise and generate plans, or other temporally structured behavioural indicators.

Generally, pattern recognition will be applicable at various hierarchical levels within a C^2 system and take two forms: identifying 'event' patterns in the state of the environment of the system from sensor data, and generating 'response' patterns which influence that environment in a way which is consistent with the operational objective of the systems. The first element of the work programme is therefore to identify examples of such mechanisms in Naval and TMD domaisn so that the potential utility of algorithms aimed at such aspects can be judged.

Representations must then be studied, particularly what types of primitives are necessary as descriptors of events, actions or states, and what sort of syntactic structures are appropriate to descriptions of event patterns or plans. This then leads to decisions about appropriate Finite Stochastic Automata structures and algorithms.

Research into the algorithms themselves requires preliminary work on scenarios to obtain data in appropriate formats.

Experimentation with prototype learning systems can then proceed, along with prototypes using grammars for analysis of event or synthesis of plans.

Relation to Programme

As a technology driven project, the research is independent of other work within the programme. There is some intersection with learning work in SP3.1.2.1 on Neural Networks and SP2.1.2.2 on rule-based learning.

Time and Effort

This research is best addressed by a University-based PhD involving three man-years of effort over a three year period, at a cost of £120k.

Inputs / Assumptions

There is a heavy dependence on the availability of suitable scenario data. This data has to be in the form of strings of state, action or event descriptors relating to objects, from which a grammar can be learnt. The implication is that some effort may need to be devoted to translating scenario data into an appropriate form.

Deliverables

- Prototype learning algorithm and parser for grammars.
- Thesis on applicability of representation and reasoning scheme to command and control.

Resources

Hardware:	Workstation	£25k
Software:	Compilers	£5k
Total:		£30k

These hardware and software resources should already be available at any appropriate contractor's site. It is not expected that ARE will need to purchase them; this work can be done at the contractor's site.

SP 4.1.1.1 Specification of Advanced Battle Management Prototype

Description

The aim of this study is to lay the foundations of a future design and implementation project that would follow on at the end of the currently planned 3 year programme. The study will take place at the end of the programme and will combine and focus the results of the other projects. It will generate a requirements specification for an advanced BMC2 (Adv BMC&CD) prototype that combines all the functional levels of command and control previously explored. It will be the initial step towards a new generation demonstrator (or demonstrators) that will encompass the lessons of the previous demonstrators but will incorporate more advanced techniques and capability.

Objectives

To produce a requirements specification for a BMC2 prototype demonstrator.

Technical Work Involved

Senior staff analysis and specification in close association with ARE/SDIO.

Tasks will include:

- establish constraints and assumptions for demonstrator;
- outline and review operational requirements - at least in the context of the demonstrator;
- analyse results of the TDS and the evaluation of the research programme;
- draw up and assess the feasible functionality of the demonstrator;
- establish outline architecture of demonstrator;
- draw up requirements specification;
- establish a costed programme for implementing the demonstrator.

Components

All aspects of applicable technology and C^2 operations will be covered by this project.

Relation to Programme

The project will be in the last year of the three year programme and will draw together the results of previous work.

Time and Effort

Total : 2 man years over 1 year

Inputs/Assumptions

The project assumes that there is sufficient confidence in the technology and the benefits to advanced C^2 to proceed with drawing up plans for a further stage in the form of an Adv BMC&CD.

At this stage it is appropriate to leave open the question of whether there will be separate Naval and TMD Adv BMC^2 Demonstrators. However, the assumption is that this decision will have been made before this project is undertaken. Some cost increase in the project may be necessary if two very distinct Demonstrators are undertaken.

Access to sources of Naval and SDI/TMD expertise as well as visibility of the results of the TDS and research programme evaluation are vital pre-requisites for this project.

Deliverables

- Operational and user requirements specification.
- Functionality and outline architecture design
- Cost estimates and project plan for implementation.

Resources

The only hardware and software required will be tools and facilities for tasks such as document creation. (£5K)

Skills and expertise to carry out this work will be in very short supply. Requirements include:

- knowledge of a wide range of enabling AI technologies(eg KBS, HCI and advanced software engineering);
- application of these in the context of C^2;
- intimate knowledge of application domains (Naval and TMD);
- experience of implementing significant sized KBS projects;
- senior staff with systems analysis and design experience.

SP 4.1.1.2 Scenario Generation and Data

Description

All experiments will require resource for scenario generation and/or interface data. This project is intended to reserve some programme resource for that activity without at this stage being too specific as to how this will be achieved for individual projects. Clearly a high level of commonality of requirement is expected and the use of other scenario generators is anticipated (eg the SDIO sponsored work at RAE/SSL and at Hunting Engineering)

Objectives

To produce the scenario data to support all research projects.

Technical Work Involved

An early exercise is needed to assess the detailed requirements of the proposed projects and to determine their needs for scenario and other input data. This will help to assess the size and scale of the work needed and could influence strongly the choice of the other research projects. For example, it may be best to drive a prototype project in a modified direction as a result of the constraints on available scenario data and the costs involved in generation.

In addition, there will be a number of separate work packages for data generation. Tasks within these work packages could include:

- writing software tools to convert and operate on data available as output from other sources (eg the RAE work on discrimination)
- the collection and analysis of relatively raw data (eg from trials or simulators)
- the production of new simulators and other software for scenario data generation.

Relation to Programme

It is an essential and early part of the programme. The assessment exercise must be started immediately in order to influence other projects.

The assessment exercise would then run continuously throughout the length of the programme and would drive the work packages that actually produce the data for projects. These packages will need to be closely linked to the timetable of other scenario generation programmes and to the input requirements of individual SANDERLING research projects.

Time and Effort

Total : 4.5 man years over 3 years

Inputs/Assumptions

The definition of scenario data requirements for many projects has yet to be determined and the source and availability of data is likely to be variable and to depend on a number of factors outside the scope of this study.

For the time being this topic is therefore included as a flag to register the need for such an activity but not to make, at this stage, a detailed estimate of the extent and cost.

However, the area is one of very high potential cost and impact on the rest of the programme. The resource allocated to this project is relatively modest, since it assumes:

- a high level of commonality between projects (at least in either the Naval or TMD domains)
- use of other scenario generators such as the SDIO sponsored work at RAE/SSL and at Hunting Engineering.
- individual projects will include the acquisition of non-scenario input data unless it has been identified as particularly general.

Deliverables

- Reports at intervals on the scenario and other data requirements and actions by the project to meet those requirements.
- Appropriate scenario and other general input data for projects.

Resources

Depending on the applicability of existing scenario generation hardware and software, there could be a need for further expenditure. At this stage it is assumed that existing facilities are suitable or will be funded separately.

Skills and expertise to carry out this project are likely to include:

- experience of scenario data generation in C^2 applications;
- knowledge of the Naval and TMD domains as appropriate;
- an understanding of the technology and needs of the other research projects in the programme;
- on-site or suitably available software and hardware facilities would be helpful.

SP 4.1.1.3 Provision of HCI Investigation/Trials Facilities

Description

HCI work such as task analysis and evaluation of the potential impact of KBS systems on the operational environment are likely to require the use of large high fidelity simulation facilities or interaction with in-service systems. Provision needs to be made for the allocation of such a resource to a number of projects.

Objectives

To provide access to operational, training and simulation facilities for HCI projects.

Technical Work Involved

A short investigation is needed initially to determine in more detail the requirements for this project and the extent to which other work such as that being carried out by AXC5 at ARE is relevant, in particular for Naval applications and HCI projects. This work would also indicate the extent to which these projects rely on other Naval resources and initiate the acquisition of those facilities.

Relation to Programme

The projects for which this work would provide facilities include the following:

SP 2.1.1.5 Optimisation of HCI Design for Tactical Displays

SP 2.1.1.6 Evaluation of the Effects of Operator Interaction with the TDS

SP 2.1.1.7 Assessment of the Man-machine Interface of the TDS

SP 2.1.1.8 Evaluation of the TDS as a Data Fusion System

SP 2.1.2.4 HCI for Situation Assessment and Resource Allocation.

These projects will require specific and relevant scenarios and simulations to be available. They assume that such input will be provided by this project or by the simulation work being undertaken by AXC5.

Time and Effort

This project has been raised to flag this issue. No effort has yet been estimated for the project on the basis that:

- the requirements are still very unclear;
- it is likely that the work of AXC5 could be used rather than duplicated;
- other facilities (training and operational), if needed, would be provided on a 'no cost' basis.

Inputs/Assumptions

Cost assumptions are made above.

The other major assumption is that the facilities are required for Naval projects only. HCI issues involved in the specifically TMD related projects will be serviced by those projects individually. However, there may be a similar, but lesser, need in terms of access to SDI simulation and test bed facilities.

The definition of the HCI research projects and the details of the work being carried out by AXT5 are the initial inputs to this project.

Deliverables

- C^2 scenarios and settings of sufficient realism to be useful to the major HCI Naval research projects.

Resources

None currently allocated.

SP 4.1.1.4 TDS Facilities Management

Description

Many of the proposed projects plan to use the TDS. To provide use of these facilities will require management that includes configuration control, facility scheduling, scenario generation, system training etc. A provision for such support should be included.

Objectives

To provide facilities management for the TDS.

Technical Work Involved

The range of tasks would include:

- software and hardware maintenance
- configuration control
- scheduling users
- supporting use for scenario generation;
- supporting use for system training.

Relation to Programme

Needs to run throughout the programme.

Time and Effort

None currently allocated here on the basis that this will be funded from specific MOD/RN resources and not the SANDERLING research programme.

It is not yet clear whether this project will cover hardware and software and to which versions and installations of the TDS it will apply.

Inputs/Assumptions

For the time being this topic is included as a flag to register the need for such an activity but not to make, at this stage, a detailed estimate of the extent and cost.

Deliverables

- Continued facilities management against a defined statement of work.

Resources

Use of the TDS and on-site staff with facilities management experience.

SP 4.1.1.5 Programme Management

Description

The research programme will require significant staff resource for its management. This project is included to ensure an allocation for such support is included in the programme.

Objectives

To provide programme management staff and facilities.

Technical Work Involved

Management and co-ordination of the complete research programme. Tasks will include:

- control and direction of individual research projects
- issuing of RFPs/ITTs and bid evaluation
- liaison with other ARE and MOD agencies
- liaison and reporting to SDIO/SDIPO
- financial monitoring and control of projects and programme
- strategy and organisation of the programme

Relation to Programme

Essential throughout the programme.

Time and Effort

Discussions and advice from those involved in managing other research programmes such as Alvey and ESPRIT suggest that programme management effort needs to be from 7 to 14% of the total budget and that one person is needed for each seven projects. There are 20 research projects in the Type A short list of recommended projects. Their value is approximately £7m of professional effort. This suggests that ARE should allocate a minimum of 2 people full time to manage and co-ordinate the programme. The minimum cost of this effort is therefore 6 man years or about £500K. As the staff are likely to be senior, then the real costs could be higher. The format could consist of the equivalent of one ARE member of staff and one supporting person from an outside contractor.

On the advice of ARE that the funding of programme management will be undertaken separately, no specific allocation of effort is included in our totals for the research programme.

Inputs/Assumptions

The programme, although managed by the ARE, will require some allocation of internal and external resource to support it adequately.

Deliverables

- Staff to provide programme management to an agreed statement of work and terms of reference.

Resources

Staff with experience of managing R&D projects and programmes, preferrably in the fields of defence, KBS and C^2.

SP 4.1.1.6 Programme Evaluation

Description

The programme will require staff resource to provide support with the evaluation of the results and achievements of projects and the programme.

Objectives

To provide staff support for programme evaluation.

Technical Work Involved

This work is closely related to project management. However, it is a separate and independent activity in the sense that it reviews and assesses the value and success of the whole programme, including the programme management. Programme evaluation will provide the support data and analysis to measure the programme and projects against their objectives.

Relation to Programme

The work would focus and highlight the results and benefits of the programme and assist in determining the way forward. As such it will include coverage of ARE Experimental Programme Research Objective (EXPRO) 7 - the extent to which the TDS falls short of that needed for a future operational system.

Time and Effort

Effort in the order of up to 1 man year over 3 years would be appropriate, but a much smaller amount of consultancy time would be an alternative. However, on advice from ARE that this would be funded elsewhere or included in programme management, we have not made an explicit allocation of resource for this work as a SANDERLING project.

Inputs/Assumptions

The programme, although evaluated by ARE and SDIO, will require some allocation of independent internal and external resource to evaluate it fully.

Deliverables

- Evaluation reports at 6 monthly or annual intervals.

Resources

Appropriate skills and experience for this task would be:

1. Independent consultancy from senior staff with experience of directing and evaluating such research programmes.

2. More junior staff for the collection and analysis of data on projects and the programme.

SP 4.1.1.7 TDS Trials Data Processing

Description

This project makes provision for the processing and reduction of data recorded during trials of the TDS. It was identified as requirement number 5.2 in ARE research programme document ARE/23.01.02/90.

Objectives

To carry out data processing and reduction on TDS trials data in order to provide ARE researchers with the information they need to analyse the results of the trials.

Technical Work Involved

Initially during the setting-to-work phase, data will be recorded from sensors and the recorded data transported to ARE and played through the system to rectify any problems. During trials, data will be recorded within the context of Naval exercises. This data will require processing/reduction in order to provide the information for leaders of TDS Objectives to analyse the results of their experiments. The work will complement that of AOT3, the ARE experimental analysis team.

Relation to Programme

This an essential work item in the experimental use of the TDS. The work should commence from the end of TDS Phase 4, following an earlier identification and estimate of the detailed needs and requirements of the project.

Time and Effort

3 man years over an elapsed time of 1.5 years.

Inputs/Assumptions

Input to the project will include:

- information/data requirements of the TDS experiments and projects;
- expected form of TDS sensors and trials output data.

Deliverables

- Data and information in the form required and specified.

Resources

Appropriate skills and experience for this task would be:

1. Experience of Trials data processing and reduction in the context of Naval C^2.
2. Knowledge of the TDS and of ARE's research and experimental programme.